

# Implementing Virtual Memory on Nachos

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## 一、实验目的

1. 了解操作系统内核、虚拟机原理
2. 加深对操作系统虚拟存储的理解
3. 练习C、C++编程

## 二、实验环境

- 计算机硬件: DELL INSPRION 600m
- 主机操作系统: Ubuntu 8.04 hardy, gnome
- 编译器: gcc 4.1.3 for i486-linux-gnu, gcc 2.95.2 for decstation-ultrix, coff2noff 1.0
- 集成开发环境: Code::Blocks 8.02
- Nachos C++ 4.1版本

## 三、简要步骤

1. 阅读资料, 了解Nachos原理
2. 设计并实现虚拟存储算法
3. 设计和制作测试程序
4. 输出并分析测试结果

## 四、虚拟存储算法

由于C++版本的Nachos存在诸多问题需要修正, 从头开始有点得不偿失。本次实验使用的Nachos源码是在上次实验修正完毕的基础上的, 但是在Makefile里关闭了-DPRIORITY\_SCHED和-DPATCH\_SYSCALLS1两个编译选项, 从而上次实验对调度算法的修改恢复了原状。

### (一)编译选项

为了方便看出哪些代码是修改过的, 我使用了#ifdef、#ifndef预处理分支, 并在Makefile的DEFINES末尾加上-DVIRTMEM。

### (二)主要数据结构

```
enum VirtMemPageStatus { //represent the type and status of a
```

```

virtual page
    vmplsInvalid, //invalid, shouldn't be accessed
    vmplsCode, //code page, read from noff binary
    vmplsData, //data page, never modified, read from noff binary
    #ifdef RDATA
    vmplsRData, //readonly-data page, read from noff binary
    #endif
    vmplsDataUninit, //uninitialized data page, never modified,
allocate and zero out
    vmplsStack, //stack page, never modified, allocate only
    vmplsMixed, //mixed page, never modified, read from noff binary
    vmplsSwap //data/rdata/mixed page, modified, read from swap area
};

```

这个枚举用来表示一个虚拟页的类型和状态，各个值区别如下：

枚举值	含义	只读属性	换入处理	换出处理
Invalid	无效		系统出错	
Code	代码段	只读	从noff文件读入	无
Data	数据段，未修改	读写	从noff文件读入	若被修改，设置为vmplsSwap并写入交换文件
RData	只读的数据	只读	从noff文件读入	无
DataUninit	未初始化的数据（bss），未修改	读写	清零	若被修改，设置为vmplsSwap并写入交换文件
Stack	堆栈区，未修改	读写	无	若被修改，设置为vmplsSwap并写入交换文件
Mixed	页内包含多个段，未修改	读写	尝试从noff文件的代码、数据、未初始化数据段读入	若被修改，设置为vmplsSwap并写入交换文件
Swap	已被换出到交换文件的页	读写	从交换文件读入	写入交换文件

```

class VirtMemPageInfo { //holds information about one page

```

```

public:
    VirtMemPageInfo();

    int virtualPage;//virtual page #

    VirtMemPageStatus status;//type & status of this page

    int swapAddr;//offset in swap area of DataSwap pages, -
1=invalid
};

const int NumVirtualPages=256;

const int NumSwapPages=64;

```

### ⊖页表的初始化

在AddrSpace::AddrSpace和AddrSpace::Load中完成。

- 所有页表项初始时valid=false，全部无效；内容不载入主存
- 初始化时要根据noff头登记每个虚页的类型
- 打开交换文件，交换文件位于文件系统中（stub或自己实现的文件系统），文件名是noff名字后面加上.swap

### ⊖内存分配策略

VirtMemAllocator类表示一种内存分配策略。

```

class VirtMemAllocator { //abstract memory allocator
public:
    virtual int Allocate() = 0; //allocate one sector, returns
virtualPage#
};

```

目前使用的默认分配策略是：

1. 从上一次分配成功的物理页开始查找
2. 如有未分配的物理页，分配之
3. 如有访问位R=0、修改位M=0的物理页，分配之
4. 如有访问位R=1、修改位M=0的物理页，分配之
5. 如有访问位R=0、修改位M=1的物理页，分配之
6. 如有访问位R=1、修改位M=1的物理页，分配之

7. 如果还是没有分配成功，出错（这几乎是不可能的）  
上述策略由VirtMemMRAllocator类实现。

```
class VirtMemMRAllocator : public VirtMemAllocator { //allocator
according to Modified,Reference bits

public:

    VirtMemMRAllocator(TranslationEntry *pageTable);

    int Allocate();

    void TimerCallback(); //timer callback, resets all Reference
bits

private:

    TranslationEntry *pageTable;

    int last_position;

    int timer_count;

    TranslationEntry **physMemStatus; //valid Translation entry
sorted by physicalPage

    void updatePhysMemStatus();

};
```

这种策略要求定期清除R位，由Alarm类调用AddrSpace::TimerCallback进而调用VirtMemMRAllocator::TimerCallback函数完成，每调用5次对所有R位清除1次。

### (五)缺页异常处理

缺页异常的原因是MIPS CPU想访问某个虚拟地址，但是这个虚拟页对应的页表项valid=0。发生缺页异常后，会进入userprog/exception.cc中的ExceptionHandler函数，并且MIPS CPU想访问的那个虚拟地址在寄存器BadVAddrReg中。此时，只需使这个虚拟页进入主存，然后令MIPS CPU重新执行原来那条指令。

```
#ifdef VIRTMEM
case PageFaultException:
{
    int badVAddr=(int)kernel->machine-
>ReadRegister(BadVAddrReg);
    int virtualPage=divRoundDown(badVAddr,PageSize);
    kernel->currentThread->space->EnsureIn(virtualPage);
    return;
}
```

```
    break;
#endif
```

其中，AddrSpace::EnsureIn函数将使得指定的虚拟页进入主存，流程如下：

1. 如果虚拟页已经在主存，直接返回
2. 调用allocator分配物理页
3. 如果分配到的物理页原来被另一虚拟页占用，换出之
4. 换入本次指定的虚拟页

```
void AddrSpace::EnsureIn(unsigned int virtualPage) {
    DEBUG(dbgAddr, "EnsureIn "<<virtualPage);
    if (this->pageTable[virtualPage].valid) return;
    int physicalPage=this->allocator->Allocate();
    for (int i=0;i<NumVirtualPages;++i)
        if (this->pageTable[i].valid && this->pageTable[i].physicalPage==physicalPage)
            this->SwapOut(i);
    this->SwapIn(virtualPage, physicalPage);
    this->DEBUGprint();
}
```

### (六)换出

换出操作由SwapOut函数完成。有关说明参见(二)主要数据结构中的表格。

```
void AddrSpace::SwapOut(unsigned int virtualPage) {
    this->DEBUGprint();
    DEBUG(dbgAddr, "SwapOut "<<virtualPage);
    ASSERT(this->pageTable[virtualPage].valid);
    bool dirty=this->pageTable[virtualPage].dirty;
    bool needsave=false;
```

```
switch (this->pageInfo[virtualPage].status) {
    case vmopsCode:
#ifdef RDATA
    case vmopsRData:
#endif
        break;
    case vmopsData:
    case vmopsDataUninit:
    case vmopsStack:
    case vmopsMixed:
        needsave=dirty;
        break;
    case vmopsSwap:
        needsave=true;
        break;
    default:
        ASSERTNOTREACHED();
}
if (needsave) {
    this->pageInfo[virtualPage].status=vmopsSwap;
    this->updateSwapStatus();
    for (int i=0;i<NumSwapPages;++i) { //find a free swap
page
        if (this->swapStatus[i]==NULL) {
            this->pageInfo[virtualPage].swapAddr=i;
            break;
        }
    }
}
```

```

        }
    }
    ASSERT(this->pageInfo[virtualPage].swapAddr>=0);
    DEBUG(dbgAddr, "    "<<virtualPage<<" saved to
swapPage"<<this->pageInfo[virtualPage].swapAddr);
    this->swapArea-
>WriteAt(VirtMemPhysStart(this,virtualPage), PageSize, this-
>pageInfo[virtualPage].swapAddr * PageSize);
}
this->pageTable[virtualPage].valid=FALSE;
}

```

## (七)换入

换入操作由SwapIn函数完成。有关说明参见(二)主要数据结构中的表格。

```

void AddrSpace::SwapIn(unsigned int virtualPage, unsigned int
physicalPage) {
    VirtMemPageInfo* p=&(this->pageInfo[virtualPage]);
    TranslationEntry* t=&(this->pageTable[virtualPage]);
    ASSERT(!t->valid);
    t->valid=true;
    t->physicalPage=physicalPage;
    switch (p->status) {
        case vmppsCode:
            DEBUG(dbgAddr, "SwapIn
"<<virtualPage<< ", "<<physicalPage<< ", vmppsCode");
            this->SwapIn_noff(&(this-
>noffH.code), virtualPage, physicalPage);
            break;

```

```

    case vmpsData:
        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsData");

        this->SwapIn_noff (&(this-
>noffH.initData), virtualPage, physicalPage);

        break;

#ifdef RDATA
    case vmpsRData:
        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsRData");

        this->SwapIn_noff (&(this-
>noffH.readonlyData), virtualPage, physicalPage);

        break;

#endif

    case vmpsDataUninit:
        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsDataUninit");

        bzero (VirtMemPhysStart (this, virtualPage), PageSize);

        break;

    case vmpsStack:
        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsStack");

        break;

    case vmpsMixed:
        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsMixed");

        this->SwapIn_mixed (virtualPage, physicalPage);

        break;

    case vmpsSwap:

```



```

        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsSwap");

        ASSERT(p->swapAddr>=0);

        this->swapArea-
>ReadAt (VirtMemPhysStart (this, virtualPage), PageSize, this-
>pageInfo[virtualPage].swapAddr * PageSize);

        break;

    default:

        DEBUG (dbgAddr, "SwapIn
"<<virtualPage<<", "<<physicalPage<<", vmpsInvalid");

        ASSERTNOTREACHED();

    }

    p->swapAddr=-1;//free the swap page

    t->readOnly=(p->status == vmpsCode || p->status ==
vmpsRData);

    t->use=false;

    t->dirty=false;

}

```

换入的难点在于从noff文件中读取。SwapIn\_noff函数可以指定的虚拟页与noff的一个段是否有重叠部分，如果有就读取这个部分

```

void AddrSpace::SwapIn_noff(Segment* segment, unsigned int
virtualPage, unsigned int physicalPage) {

    //determine whether segment overlaps this page, if so then
load its contents

    if (segment->size<=0) return;

    int startPage=divRoundDown(segment->virtualAddr, PageSize);

    int endPage=divRoundDown(segment->virtualAddr+segment->size-
1, PageSize);

    if (startPage>virtualPage || endPage<virtualPage)

```

```

return;//no overlap

    bool isStart=virtualPage==startPage;

    bool isEnd=virtualPage==endPage;

    int offsetStart=isStart?(segment->virtualAddr % PageSize):0;

    int offsetEnd=isEnd?((segment->virtualAddr+segment->size-
1) % PageSize):PageSize-1;

    int size=offsetEnd-offsetStart+1;

    ASSERT(size>0);

    int position=segment->inFileAddr+(virtualPage-
startPage)*PageSize+offsetStart;

    this->executable-
>ReadAt (VirtMemPhysStart (this,virtualPage),size,position);
}

```

如果碰上了vmpsMixed的虚页，只好把每个段都试一遍了。也许还会包含“未初始化数据”段的内容，所以先全部清零。

```

void AddrSpace::SwapIn_mixed(unsigned int virtualPage, unsigned
int physicalPage) {

    //zero out the page in case there is uninitData

    bzero(VirtMemPhysStart (this,physicalPage),PageSize);

    //try load from each segment

    this->SwapIn_noff(&(this-
>noffH.code),virtualPage,physicalPage);

    this->SwapIn_noff(&(this-
>noffH.initData),virtualPage,physicalPage);

    #ifdef RDATA

    this->SwapIn_noff(&(this-
>noffH.readonlyData),virtualPage,physicalPage);

    #endif

}

```

## 五、程序运行结果

现在我们已经有了虚拟存储功能，可以测试这个程序了。为了方便测试，Makefile里加上-DVIRTMEM\_TEST就可以把实页数、虚页数、交换文件内页数都减小。

### (一)测试用例: sunny2.c

一个没有实际意义(dummy)的小程序。

```
#include "syscall.h"

int a[100];

int i=1;

int main() {
    for (i=0;i<100;i+=20) {
        a[i]=i;
        a[i+5];
    }
    for (i=0;i<100;i+=20) {
        a[i+1]=Add(a[i],35-2*i);
    }
    Halt();
}
```

### (二)执行测试用例

为了方便的编译和执行测试用例，创建了几个shell脚本。

工作时只需先cd到test/目录，然后：

- ./build，这个脚本会cd到build.linux目录，执行make，然后cd回来

- ./run, 这个脚本根据预设参数执行sunny2.noff
- ./runlog, 这个脚本根据预设参数执行sunny2.noff, 把stdout和stderr重定向到output.txt文件里
- make, 是一个标准命令, 编译测试用例

其中runlog的代码如下:

```
../build.linux/nachos -d au -x sunny2.noff > output.txt 2>&1
```

这是以带调试信息的方式启动nachos并执行sunny.noff测试用例, 调试信息选择dbgAddr和dbgSys两种

执行一次./runlog, 就可以获得输出结果了!

### (=)结果分析

查看output.txt中的输出, 真的非常.....长.....长.....长啊 (请读者注意看我标了颜色的部分, 其他一扫而过):

```
tests summary: ok:0
```

```
Initializing address space: 16, 2048
```

```
Initializing code segment.
```

```
Initializing data segment.
```

```
Initializing uninitialized data segment.
```

```
Initializing stack segment.
```

```
$ vp0=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp2=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp3=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
```

```
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
```

```
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
```

```
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

读入noff文件后，每个虚页都是valid=0、并被标上了类型/状态。这里0~4是代码页，5是数据页，6~9是未初始化数据页，10~15是堆栈，16~23无效。

```
Initializing stack pointer: 2032
```

```
Reading VA 0, size 4
```

```
Translate 0 , read
```

```
Invalid virtual page # 0
```

```
Received Exception 2 type: 0
```

CPU想读取地址0上的指令，发生缺页异常。

```
MRAllocator::Allocate
```

```
SwapIn 0,0,vmpsCode
```

分配到了物理页0, 换入

```
$ vp0=>0, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp3=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 0, size 4

```
Translate 0 , read
phys addr = 0
value read = 201326688
```

换入后，再次读取同一个地址。

```
Reading VA 4, size 4
Translate 4 , read
phys addr = 4
value read = 0
Reading VA 384, size 4
Translate 384 , read
Invalid virtual page # 384
Received Exception 2 type: 0
```

```
EnsureIn 3
MRAllocator::Allocate
SwapIn 3,1,vmpsCode
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 384, size 4
Translate 384 , read
phys addr = 128
value read = 666763232
Reading VA 388, size 4
Translate 388 , read
phys addr = 132
value read = -1346437096
Writing VA 2024, size 4, value 8
Translate 2024 , write
Invalid virtual page # 2024
Received Exception 2 type: 0
```

```
EnsureIn 15
MRAllocator::Allocate
SwapIn 15,2,vmpsStack
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=0, M=0, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 388, size 4
```

```
    Translate 388 , read
```

```
phys addr = 132
```

```
    value read = -1346437096
```

```
Writing VA 2024, size 4, value 8
```

```
    Translate 2024 , write
```

```
phys addr = 360
```

```
Reading VA 392, size 4
```

```
    Translate 392 , read
```

```
phys addr = 136
```

```
    value read = -1347354604
```

```
Writing VA 2020, size 4, value 0
```

```
    Translate 2020 , write
```

```
phys addr = 356
```

```
Reading VA 396, size 4
```

```
    Translate 396 , read
```

```
phys addr = 140
```

```
    value read = 201326684
```

```
Reading VA 400, size 4
```

```
    Translate 400 , read
```

```
phys addr = 144
```

```
    value read = -1347420144
```

```
Writing VA 2016, size 4, value 0
```

```
    Translate 2016 , write
```

```
phys addr = 352
```

```
Reading VA 368, size 4
```

```
    Translate 368 , read
```

```
Invalid virtual page # 368
```

```
Received Exception 2 type: 0
```

```
EnsureIn 2
```

```
MRAllocator::Allocate
```

```
SwapIn 2,3,vmpsCode
```



```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=0, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 368, size 4
    Translate 368 , read
phys addr = 496
    value read = 65011720
Reading VA 372, size 4
    Translate 372 , read
phys addr = 500
    value read = 0
Reading VA 404, size 4
    Translate 404 , read
phys addr = 148
    value read = 1006895104
Reading VA 408, size 4
    Translate 408 , read
phys addr = 152
    value read = 612631296
Reading VA 412, size 4
    Translate 412 , read
phys addr = 156
    value read = 1006698496
Reading VA 416, size 4
    Translate 416 , read
phys addr = 160
    value read = -1407188352
Writing VA 640, size 4, value 0
    Translate 640 , write
Invalid virtual page # 640
Received Exception 2 type: 0

EnsureIn 5
MRAllocator::Allocate
SwapIn 5,4,vmpsData
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
```

```
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 416, size 4
    Translate 416 , read
phys addr = 160
    value read = -1407188352
Writing VA 640, size 4, value 0
    Translate 640 , write
phys addr = 512
Reading VA 420, size 4
    Translate 420 , read
phys addr = 164
    value read = 1006829568
Reading VA 424, size 4
    Translate 424 , read
phys addr = 168
    value read = -1939668352
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 0
Reading VA 428, size 4
    Translate 428 , read
phys addr = 172
    value read = 0
Reading VA 432, size 4
    Translate 432 , read
phys addr = 176
    value read = 200832
Reading VA 436, size 4
    Translate 436 , read
phys addr = 180
    value read = 4460577
Reading VA 440, size 4
    Translate 440 , read
phys addr = 184
```

```
    value read = -1404895232
Writing VA 768, size 4, value 0
    Translate 768 , write
Invalid virtual page # 768
Received Exception 2 type: 768
```

```
EnsureIn 6
```

```
MRAllocator::Allocate
```

```
SwapIn 6,5,vmpsDataUninit
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 440, size 4
```

```
    Translate 440 , read
```

```
phys addr = 184
```

```
    value read = -1404895232
```

```
Writing VA 768, size 4, value 0
```

```
    Translate 768 , write
```

```
phys addr = 640
```

```
Reading VA 444, size 4
```

```
    Translate 444 , read
```

```
phys addr = 188
```

```
    value read = 610467860
```

```
Reading VA 448, size 4
```

```
    Translate 448 , read
```

```
phys addr = 192
```

```
    value read = 1006698496
```

```
Reading VA 452, size 4
```

```
    Translate 452 , read
```

```
phys addr = 196
```

```
    value read = -1406991744
```

```
Writing VA 640, size 4, value 20
```

```
    Translate 640 , write
```

```
phys addr = 512
```

```
Reading VA 456, size 4
```

```
    Translate 456 , read
```

```
phys addr = 200
  value read = 677576804
Reading VA 460, size 4
  Translate 460 , read
phys addr = 204
  value read = 341901301
Reading VA 464, size 4
  Translate 464 , read
phys addr = 208
  value read = 605093923
Reading VA 420, size 4
  Translate 420 , read
phys addr = 164
  value read = 1006829568
Reading VA 424, size 4
  Translate 424 , read
phys addr = 168
  value read = -1939668352
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 20
Reading VA 428, size 4
  Translate 428 , read
phys addr = 172
  value read = 0
Reading VA 432, size 4
  Translate 432 , read
phys addr = 176
  value read = 200832
Reading VA 436, size 4
  Translate 436 , read
phys addr = 180
  value read = 4460577
Reading VA 440, size 4
  Translate 440 , read
phys addr = 184
  value read = -1404895232
Writing VA 848, size 4, value 20
  Translate 848 , write
phys addr = 720
Reading VA 444, size 4
  Translate 444 , read
phys addr = 188
  value read = 610467860
Reading VA 448, size 4
  Translate 448 , read
phys addr = 192
  value read = 1006698496
Reading VA 452, size 4
  Translate 452 , read
phys addr = 196
  value read = -1406991744
Writing VA 640, size 4, value 40
  Translate 640 , write
phys addr = 512
Reading VA 456, size 4
```

```
Translate 456 , read
phys addr = 200
value read = 677576804
Reading VA 460, size 4
Translate 460 , read
phys addr = 204
value read = 341901301
Reading VA 464, size 4
Translate 464 , read
phys addr = 208
value read = 605093923
Reading VA 420, size 4
Translate 420 , read
phys addr = 164
value read = 1006829568
Reading VA 424, size 4
Translate 424 , read
phys addr = 168
value read = -1939668352
Reading VA 640, size 4
Translate 640 , read
phys addr = 512
value read = 40
Reading VA 428, size 4
Translate 428 , read
phys addr = 172
value read = 0
Reading VA 432, size 4
Translate 432 , read
phys addr = 176
value read = 200832
Reading VA 436, size 4
Translate 436 , read
phys addr = 180
value read = 4460577
Reading VA 440, size 4
Translate 440 , read
phys addr = 184
value read = -1404895232
Writing VA 928, size 4, value 40
Translate 928 , write
Invalid virtual page # 928
Received Exception 2 type: 928
```

EnsureIn 7

MRAllocator::Allocate

SwapIn 7,6,vmpsDataUninit

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
```

```
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 440, size 4
    Translate 440 , read
phys addr = 184
    value read = -1404895232
Writing VA 928, size 4, value 40
    Translate 928 , write
phys addr = 800
Reading VA 444, size 4
    Translate 444 , read
phys addr = 188
    value read = 610467860
Reading VA 448, size 4
    Translate 448 , read
phys addr = 192
    value read = 1006698496
Reading VA 452, size 4
    Translate 452 , read
phys addr = 196
    value read = -1406991744
Writing VA 640, size 4, value 60
    Translate 640 , write
phys addr = 512
Reading VA 456, size 4
    Translate 456 , read
phys addr = 200
    value read = 677576804
Reading VA 460, size 4
    Translate 460 , read
phys addr = 204
    value read = 341901301
Reading VA 464, size 4
    Translate 464 , read
phys addr = 208
    value read = 605093923
Reading VA 420, size 4
    Translate 420 , read
phys addr = 164
    value read = 1006829568
Reading VA 424, size 4
    Translate 424 , read
phys addr = 168
    value read = -1939668352
Reading VA 640, size 4
```

```
Translate 640 , read
phys addr = 512
value read = 60
Reading VA 428, size 4
Translate 428 , read
phys addr = 172
value read = 0
Reading VA 432, size 4
Translate 432 , read
phys addr = 176
value read = 200832
Reading VA 436, size 4
Translate 436 , read
phys addr = 180
value read = 4460577
Reading VA 440, size 4
Translate 440 , read
phys addr = 184
value read = -1404895232
Writing VA 1008, size 4, value 60
Translate 1008 , write
phys addr = 880
Reading VA 444, size 4
Translate 444 , read
phys addr = 188
value read = 610467860
Reading VA 448, size 4
Translate 448 , read
phys addr = 192
value read = 1006698496
Reading VA 452, size 4
Translate 452 , read
phys addr = 196
value read = -1406991744
Writing VA 640, size 4, value 80
Translate 640 , write
phys addr = 512
Reading VA 456, size 4
Translate 456 , read
phys addr = 200
value read = 677576804
Reading VA 460, size 4
Translate 460 , read
phys addr = 204
value read = 341901301
Reading VA 464, size 4
Translate 464 , read
phys addr = 208
value read = 605093923
Reading VA 420, size 4
Translate 420 , read
phys addr = 164
value read = 1006829568
Reading VA 424, size 4
Translate 424 , read
phys addr = 168
value read = -1939668352
```

```
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 80
Reading VA 428, size 4
  Translate 428 , read
phys addr = 172
  value read = 0
Reading VA 432, size 4
  Translate 432 , read
phys addr = 176
  value read = 200832
Reading VA 436, size 4
  Translate 436 , read
phys addr = 180
  value read = 4460577
Reading VA 440, size 4
  Translate 440 , read
phys addr = 184
  value read = -1404895232
Writing VA 1088, size 4, value 80
```

```
  Translate 1088 , write
```

```
Invalid virtual page # 1088
```

```
Received Exception 2 type: 1088
```

```
EnsureIn 8
```

```
MRAllocator::Allocate
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
```



```
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

现在7个物理页都满了，只好按策略选一个换出。

SwapOut 0

SwapIn 8,0,vmpsDataUninit

```
$ vp0=>0, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=0, M=0, status=4, swap-1
```

\$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1  
\$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

Reading VA 440, size 4

Translate 440 , read

phys addr = 184

value read = -1404895232

Writing VA 1088, size 4, value 80

Translate 1088 , write

phys addr = 64

Reading VA 444, size 4

Translate 444 , read

phys addr = 188

value read = 610467860

Reading VA 448, size 4

Translate 448 , read

phys addr = 192

value read = 1006698496

Reading VA 452, size 4  
    Translate 452 , read  
phys addr = 196  
    value read = -1406991744  
Writing VA 640, size 4, value 100  
    Translate 640 , write  
phys addr = 512  
Reading VA 456, size 4  
    Translate 456 , read  
phys addr = 200  
    value read = 677576804  
Reading VA 460, size 4  
    Translate 460 , read  
phys addr = 204  
    value read = 341901301  
Reading VA 464, size 4  
    Translate 464 , read  
phys addr = 208  
    value read = 605093923  
Reading VA 468, size 4  
    Translate 468 , read  
phys addr = 212  
    value read = 1006698496  
Reading VA 472, size 4  
    Translate 472 , read  
phys addr = 216  
    value read = -1407188352  
Writing VA 640, size 4, value 0  
    Translate 640 , write  
phys addr = 512  
Reading VA 476, size 4  
    Translate 476 , read  
phys addr = 220  
    value read = 1007681536  
Reading VA 480, size 4  
    Translate 480 , read  
phys addr = 224  
    value read = 638583552  
Reading VA 484, size 4  
    Translate 484 , read  
phys addr = 228  
    value read = 1006960640  
Reading VA 488, size 4  
    Translate 488 , read  
phys addr = 232  
    value read = -1935342976  
Reading VA 640, size 4  
    Translate 640 , read  
phys addr = 512  
    value read = 0  
Reading VA 492, size 4  
    Translate 492 , read  
phys addr = 236  
    value read = 0  
Reading VA 496, size 4  
    Translate 496 , read  
phys addr = 240

```
value read = 331904
Reading VA 500, size 4
  Translate 500 , read
phys addr = 244
  value read = 5247009
VirtMemMRAllocator::TimerCallback 0
Reading VA 504, size 4
  Translate 504 , read
phys addr = 248
  value read = 337984
Reading VA 508, size 4
  Translate 508 , read
phys addr = 252
  value read = -1941700608
Reading VA 768, size 4
  Translate 768 , read
phys addr = 640
  value read = 0
Reading VA 512, size 4
  Translate 512 , read
Invalid virtual page # 512
Received Exception 2 type: 768
```

EnsureIn 4

MRAllocator::Allocate

```
$ vp0=>0, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 3

SwapIn 4,1,vmpsCode

```
$ vp0=>0, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
```

```
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 512, size 4
    Translate 512 , read
phys addr = 128
    value read = 201326600
Reading VA 516, size 4
    Translate 516 , read
phys addr = 132
    value read = 35989539
Reading VA 32, size 4
    Translate 32 , read
Invalid virtual page # 32
Received Exception 2 type: 768
```

EnsureIn 0

MRAllocator::Allocate

```
$ vp0=>0, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
SwapOut 4
SwapIn 0,1,vmpsCode
$ vp0=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 32, size 4
    Translate 32 , read
phys addr = 160
    value read = 604110890
Reading VA 36, size 4
    Translate 36 , read
phys addr = 164
    value read = 12
Received Exception 1 type: 42

Add 0 + 35

Add returning with 35

Reading VA 40, size 4
    Translate 40 , read
phys addr = 168
    value read = 65011720
Reading VA 44, size 4
    Translate 44 , read
phys addr = 172
    value read = 0
Reading VA 520, size 4
    Translate 520 , read
Invalid virtual page # 520
Received Exception 2 type: 35

EnsureIn 4
MRAllocator::Allocate
$ vp0=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 0
```

SwapIn 4,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 520, size 4

Translate 520 , read

phys addr = 136

value read = 1006895104

Reading VA 524, size 4

Translate 524 , read

phys addr = 140

value read = -1937505664

Reading VA 640, size 4

```
Translate 640 , read
phys addr = 512
value read = 0
Reading VA 528, size 4
Translate 528 , read
phys addr = 144
value read = 0
Reading VA 532, size 4
Translate 532 , read
phys addr = 148
value read = 612564993
Reading VA 536, size 4
Translate 536 , read
phys addr = 152
value read = 202880
Reading VA 540, size 4
Translate 540 , read
phys addr = 156
value read = 7346209
Reading VA 544, size 4
Translate 544 , read
phys addr = 160
value read = 612630548
Reading VA 548, size 4
Translate 548 , read
phys addr = 164
value read = -1402863616
Writing VA 772, size 4, value 35
Translate 772 , write
phys addr = 644
Reading VA 552, size 4
Translate 552 , read
phys addr = 168
value read = 1006698496
Reading VA 556, size 4
Translate 556 , read
phys addr = 172
value read = -1406926208
Writing VA 640, size 4, value 20
Translate 640 , write
phys addr = 512
Reading VA 560, size 4
Translate 560 , read
phys addr = 176
value read = 679739492
Reading VA 564, size 4
Translate 564 , read
phys addr = 180
value read = 343998443
Reading VA 568, size 4
Translate 568 , read
phys addr = 184
value read = 0
Reading VA 484, size 4
Translate 484 , read
Invalid virtual page # 484
Received Exception 2 type: 35
```



EnsureIn 3

MRAAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 4

SwapIn 3,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 484, size 4

Translate 484 , read

phys addr = 228

value read = 1006960640

```
Reading VA 488, size 4
  Translate 488 , read
phys addr = 232
  value read = -1935342976
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 20
Reading VA 492, size 4
  Translate 492 , read
phys addr = 236
  value read = 0
Reading VA 496, size 4
  Translate 496 , read
phys addr = 240
  value read = 331904
Reading VA 500, size 4
  Translate 500 , read
phys addr = 244
  value read = 5247009
Reading VA 504, size 4
  Translate 504 , read
phys addr = 248
  value read = 337984
Reading VA 508, size 4
  Translate 508 , read
phys addr = 252
  value read = -1941700608
Reading VA 848, size 4
  Translate 848 , read
phys addr = 720
  value read = 20
Reading VA 512, size 4
  Translate 512 , read
Invalid virtual page # 512
Received Exception 2 type: 848
```

EnsureIn 4

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 3

SwapIn 4,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 512, size 4

Translate 512 , read

phys addr = 128

value read = 201326600

Reading VA 516, size 4

Translate 516 , read

phys addr = 132

value read = 35989539

Reading VA 32, size 4

Translate 32 , read

Invalid virtual page # 32

Received Exception 2 type: 848

EnsureIn 0

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
```

```
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 4

SwapIn 0,1,vmpsCode

```
$ vp0=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 32, size 4

Translate 32 , read

phys addr = 160

value read = 604110890

Reading VA 36, size 4

Translate 36 , read

phys addr = 164

value read = 12

Received Exception 1 type: 42

Add 20 + -5

Add returning with 15

Reading VA 40, size 4

Translate 40 , read

phys addr = 168

```
value read = 65011720
Reading VA 44, size 4
  Translate 44 , read
phys addr = 172
value read = 0
Reading VA 520, size 4
  Translate 520 , read
Invalid virtual page # 520
Received Exception 2 type: 15
```

```
EnsureIn 4
```

```
MRAllocator::Allocate
```

```
$ vp0=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
SwapOut 0
```

```
SwapIn 4,1,vmpsCode
```

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 520, size 4
    Translate 520 , read
phys addr = 136
    value read = 1006895104
Reading VA 524, size 4
    Translate 524 , read
phys addr = 140
    value read = -1937505664
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 20
Reading VA 528, size 4
    Translate 528 , read
phys addr = 144
    value read = 0
Reading VA 532, size 4
    Translate 532 , read
phys addr = 148
    value read = 612564993
Reading VA 536, size 4
    Translate 536 , read
phys addr = 152
    value read = 202880
Reading VA 540, size 4
    Translate 540 , read
phys addr = 156
    value read = 7346209
Reading VA 544, size 4
    Translate 544 , read
phys addr = 160
    value read = 612630548
Reading VA 548, size 4
    Translate 548 , read
phys addr = 164
    value read = -1402863616
Writing VA 852, size 4, value 15
    Translate 852 , write
phys addr = 724
Reading VA 552, size 4
    Translate 552 , read
phys addr = 168
    value read = 1006698496
Reading VA 556, size 4
    Translate 556 , read
phys addr = 172
    value read = -1406926208
Writing VA 640, size 4, value 40
    Translate 640 , write
phys addr = 512
Reading VA 560, size 4
    Translate 560 , read
```

```
phys addr = 176
  value read = 679739492
Reading VA 564, size 4
  Translate 564 , read
phys addr = 180
  value read = 343998443
Reading VA 568, size 4
  Translate 568 , read
phys addr = 184
  value read = 0
Reading VA 484, size 4
  Translate 484 , read
Invalid virtual page # 484
Received Exception 2 type: 15
```

EnsureIn 3

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 4

SwapIn 3,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
```

```
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 484, size 4
    Translate 484 , read
phys addr = 228
    value read = 1006960640
Reading VA 488, size 4
    Translate 488 , read
phys addr = 232
    value read = -1935342976
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 40
Reading VA 492, size 4
    Translate 492 , read
phys addr = 236
    value read = 0
Reading VA 496, size 4
    Translate 496 , read
phys addr = 240
    value read = 331904
Reading VA 500, size 4
    Translate 500 , read
phys addr = 244
    value read = 5247009
Reading VA 504, size 4
    Translate 504 , read
phys addr = 248
    value read = 337984
Reading VA 508, size 4
    Translate 508 , read
phys addr = 252
    value read = -1941700608
Reading VA 928, size 4
    Translate 928 , read
phys addr = 800
    value read = 40
Reading VA 512, size 4
    Translate 512 , read
Invalid virtual page # 512
Received Exception 2 type: 928

EnsureIn 4
MRAllocator::Allocate
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
```



\$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1  
\$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1  
\$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1  
\$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1  
\$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1  
\$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1  
\$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

SwapOut 3

SwapIn 4,1,vmpsCode

\$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1  
\$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1  
\$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1  
\$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1  
\$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1  
\$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1  
\$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1  
\$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1  
\$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1  
\$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

Reading VA 512, size 4

Translate 512 , read

phys addr = 128

value read = 201326600

Reading VA 516, size 4

Translate 516 , read

phys addr = 132

value read = 35989539

Reading VA 32, size 4

Translate 32 , read

Invalid virtual page # 32

Received Exception 2 type: 928

EnsureIn 0

MRAAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 4

SwapIn 0,1,vmpsCode

```
$ vp0=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 32, size 4

Translate 32 , read

phys addr = 160

```
value read = 604110890
Reading VA 36, size 4
  Translate 36 , read
phys addr = 164
  value read = 12
Received Exception 1 type: 42
```

```
Add 40 + -45
```

```
Add returning with -5
```

```
Reading VA 40, size 4
  Translate 40 , read
phys addr = 168
  value read = 65011720
Reading VA 44, size 4
  Translate 44 , read
phys addr = 172
  value read = 0
Reading VA 520, size 4
  Translate 520 , read
Invalid virtual page # 520
Received Exception 2 type: -5
```

```
EnsureIn 4
```

```
MRAllocator::Allocate
```

```
$ vp0=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
SwapOut 0
```

```
SwapIn 4,1,vmpsCode
```

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
```

```
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 520, size 4
    Translate 520 , read
phys addr = 136
    value read = 1006895104
Reading VA 524, size 4
    Translate 524 , read
phys addr = 140
    value read = -1937505664
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 40
Reading VA 528, size 4
    Translate 528 , read
phys addr = 144
    value read = 0
Reading VA 532, size 4
    Translate 532 , read
phys addr = 148
    value read = 612564993
Reading VA 536, size 4
    Translate 536 , read
phys addr = 152
    value read = 202880
Reading VA 540, size 4
    Translate 540 , read
phys addr = 156
    value read = 7346209
Reading VA 544, size 4
    Translate 544 , read
phys addr = 160
    value read = 612630548
Reading VA 548, size 4
    Translate 548 , read
phys addr = 164
    value read = -1402863616
Writing VA 932, size 4, value -5
    Translate 932 , write
```

```
phys addr = 804
Reading VA 552, size 4
    Translate 552 , read
phys addr = 168
    value read = 1006698496
VirtMemMRAllocator::TimerCallback 1
Reading VA 556, size 4
    Translate 556 , read
phys addr = 172
    value read = -1406926208
Writing VA 640, size 4, value 60
    Translate 640 , write
phys addr = 512
Reading VA 560, size 4
    Translate 560 , read
phys addr = 176
    value read = 679739492
Reading VA 564, size 4
    Translate 564 , read
phys addr = 180
    value read = 343998443
Reading VA 568, size 4
    Translate 568 , read
phys addr = 184
    value read = 0
Reading VA 484, size 4
    Translate 484 , read
Invalid virtual page # 484
Received Exception 2 type: -5
```

EnsureIn 3

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 4
```

```
SwapIn 3,1,vmpsCode
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 484, size 4
    Translate 484 , read
phys addr = 228
    value read = 1006960640
Reading VA 488, size 4
    Translate 488 , read
phys addr = 232
    value read = -1935342976
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 60
Reading VA 492, size 4
    Translate 492 , read
phys addr = 236
    value read = 0
Reading VA 496, size 4
    Translate 496 , read
phys addr = 240
    value read = 331904
Reading VA 500, size 4
    Translate 500 , read
phys addr = 244
    value read = 5247009
Reading VA 504, size 4
    Translate 504 , read
phys addr = 248
    value read = 337984
Reading VA 508, size 4
    Translate 508 , read
phys addr = 252
    value read = -1941700608
```

```
Reading VA 1008, size 4
  Translate 1008 , read
phys addr = 880
  value read = 60
Reading VA 512, size 4
  Translate 512 , read
Invalid virtual page # 512
Received Exception 2 type: 1008
```

```
EnsureIn 4
```

```
MRAllocator::Allocate
```

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
SwapOut 3
```

```
SwapIn 4,1,vmpsCode
```

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 512, size 4
    Translate 512 , read
phys addr = 128
    value read = 201326600
Reading VA 516, size 4
    Translate 516 , read
phys addr = 132
    value read = 35989539
Reading VA 32, size 4
    Translate 32 , read
Invalid virtual page # 32
Received Exception 2 type: 1008
```

EnsureIn 0

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 4
SwapIn 0,1,vmpsCode
$ vp0=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
```



```
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 32, size 4

Translate 32 , read

phys addr = 160

value read = 604110890

Reading VA 36, size 4

Translate 36 , read

phys addr = 164

value read = 12

Received Exception 1 type: 42

Add 60 + -85

Add returning with -25

Reading VA 40, size 4

Translate 40 , read

phys addr = 168

value read = 65011720

Reading VA 44, size 4

Translate 44 , read

phys addr = 172

value read = 0

Reading VA 520, size 4

Translate 520 , read

Invalid virtual page # 520

Received Exception 2 type: -25

EnsureIn 4

MRAAllocator::Allocate

```
$ vp0=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
```

```
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 0
SwapIn 4,1,vmpsCode
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 520, size 4
    Translate 520 , read
phys addr = 136
    value read = 1006895104
Reading VA 524, size 4
    Translate 524 , read
phys addr = 140
    value read = -1937505664
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 60
Reading VA 528, size 4
    Translate 528 , read
phys addr = 144
    value read = 0
Reading VA 532, size 4
    Translate 532 , read
phys addr = 148
    value read = 612564993
Reading VA 536, size 4
    Translate 536 , read
phys addr = 152
```

```
    value read = 202880
Reading VA 540, size 4
    Translate 540 , read
phys addr = 156
    value read = 7346209
Reading VA 544, size 4
    Translate 544 , read
phys addr = 160
    value read = 612630548
Reading VA 548, size 4
    Translate 548 , read
phys addr = 164
    value read = -1402863616
Writing VA 1012, size 4, value -25
    Translate 1012 , write
phys addr = 884
Reading VA 552, size 4
    Translate 552 , read
phys addr = 168
    value read = 1006698496
Reading VA 556, size 4
    Translate 556 , read
phys addr = 172
    value read = -1406926208
Writing VA 640, size 4, value 80
    Translate 640 , write
phys addr = 512
Reading VA 560, size 4
    Translate 560 , read
phys addr = 176
    value read = 679739492
Reading VA 564, size 4
    Translate 564 , read
phys addr = 180
    value read = 343998443
Reading VA 568, size 4
    Translate 568 , read
phys addr = 184
    value read = 0
Reading VA 484, size 4
    Translate 484 , read
Invalid virtual page # 484
Received Exception 2 type: -25
```

EnsureIn 3

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
```

```
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 4

SwapIn 3,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 484, size 4

Translate 484 , read

phys addr = 228

value read = 1006960640

Reading VA 488, size 4

Translate 488 , read

phys addr = 232

value read = -1935342976

Reading VA 640, size 4

Translate 640 , read

phys addr = 512

value read = 80

Reading VA 492, size 4

Translate 492 , read

phys addr = 236

value read = 0

Reading VA 496, size 4

Translate 496 , read

```
phys addr = 240
  value read = 331904
Reading VA 500, size 4
  Translate 500 , read
phys addr = 244
  value read = 5247009
Reading VA 504, size 4
  Translate 504 , read
phys addr = 248
  value read = 337984
Reading VA 508, size 4
  Translate 508 , read
phys addr = 252
  value read = -1941700608
Reading VA 1088, size 4
  Translate 1088 , read
phys addr = 64
  value read = 80
Reading VA 512, size 4
  Translate 512 , read
Invalid virtual page # 512
Received Exception 2 type: 1088
```

EnsureIn 4

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

SwapOut 3

SwapIn 4,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
```

```
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 512, size 4
    Translate 512 , read
phys addr = 128
    value read = 201326600
Reading VA 516, size 4
    Translate 516 , read
phys addr = 132
    value read = 35989539
Reading VA 32, size 4
    Translate 32 , read
Invalid virtual page # 32
Received Exception 2 type: 1088
```

EnsureIn 0

MRAllocator::Allocate

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
SwapOut 4
SwapIn 0,1,vmpsCode
$ vp0=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 32, size 4
    Translate 32 , read
phys addr = 160
    value read = 604110890
Reading VA 36, size 4
    Translate 36 , read
phys addr = 164
    value read = 12
Received Exception 1 type: 42

Add 80 + -125

Add returning with -45

Reading VA 40, size 4
    Translate 40 , read
phys addr = 168
    value read = 65011720
Reading VA 44, size 4
    Translate 44 , read
phys addr = 172
    value read = 0
Reading VA 520, size 4
    Translate 520 , read
Invalid virtual page # 520
Received Exception 2 type: -45

EnsureIn 4
MRAllocator::Allocate
$ vp0=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
```

```
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 0
```

SwapIn 4,1,vmpsCode

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 520, size 4

Translate 520 , read

phys addr = 136

value read = 1006895104

Reading VA 524, size 4

Translate 524 , read

phys addr = 140

value read = -1937505664

Reading VA 640, size 4



```
    Translate 640 , read
phys addr = 512
    value read = 80
Reading VA 528, size 4
    Translate 528 , read
phys addr = 144
    value read = 0
Reading VA 532, size 4
    Translate 532 , read
phys addr = 148
    value read = 612564993
Reading VA 536, size 4
    Translate 536 , read
phys addr = 152
    value read = 202880
Reading VA 540, size 4
    Translate 540 , read
phys addr = 156
    value read = 7346209
Reading VA 544, size 4
    Translate 544 , read
phys addr = 160
    value read = 612630548
Reading VA 548, size 4
    Translate 548 , read
phys addr = 164
    value read = -1402863616
Writing VA 1092, size 4, value -45
    Translate 1092 , write
phys addr = 68
Reading VA 552, size 4
    Translate 552 , read
phys addr = 168
    value read = 1006698496
Reading VA 556, size 4
    Translate 556 , read
phys addr = 172
    value read = -1406926208
Writing VA 640, size 4, value 100
    Translate 640 , write
phys addr = 512
Reading VA 560, size 4
    Translate 560 , read
phys addr = 176
    value read = 679739492
Reading VA 564, size 4
    Translate 564 , read
phys addr = 180
    value read = 343998443
Reading VA 568, size 4
    Translate 568 , read
phys addr = 184
    value read = 0
Reading VA 572, size 4
    Translate 572 , read
phys addr = 188
    value read = 201326596
```

```
Reading VA 576, size 4
  Translate 576 , read
phys addr = 192
  value read = 0
Reading VA 16, size 4
  Translate 16 , read
Invalid virtual page # 16
Received Exception 2 type: -45
```

```
EnsureIn 0
```

```
MRAllocator::Allocate
```

```
$ vp0=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
SwapOut 4
```

```
SwapIn 0,1,vmpsCode
```

```
$ vp0=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp4=>1, valid=0, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp8=>0, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 16, size 4
```

```
    Translate 16 , read
```

```
phys addr = 144
```

```
    value read = 604110848
```

```
Reading VA 20, size 4
```

```
    Translate 20 , read
```

```
phys addr = 148
```

```
    value read = 12
```

```
Received Exception 1 type: 0
```

```
Shutdown, initiated by user program.
```

```
Machine halting!
```

```
Ticks: total 278, idle 0, system 40, user 238
```

```
Disk I/O: reads 0, writes 0
```

```
Console I/O: reads 0, writes 0
```

```
Paging: faults 28
```

```
Network I/O: packets received 0, sent 0
```

```
缺页异常: 28次
```

上述测试用例的输出结果展现了大部分设计的功能，输出及注释已经明确的体现了本实验设计的正确性。

但是，本测试用例及输出没能体现换出到交换文件。如果进一步减小物理页数，缺页异常明显增多，输出文件膨胀到近百兆程序仍不能结束。为了演示交换文件特性，增加了一个

-DVIRTMEM\_SWAPTEST编译选项，设定此选项后MR内存分配算法将在没有空闲物理页时优先换出M=1的页面。此时获得的output.txt内容如下：

```
tests summary: ok:0
Initializing address space: 16, 2048
Initializing code segment.
Initializing data segment.
Initializing uninitialized data segment.
Initializing stack segment.
$ vp0=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp1=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp3=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp4=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>>0, valid=0, R=0, M=0, status=5, swap-1
$ vp16=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>>0, valid=0, R=0, M=0, status=0, swap-1
Initializing stack pointer: 2032
Reading VA 0, size 4
    Translate 0 , read
Invalid virtual page # 0
Received Exception 2 type: 0

EnsureIn 0
MRAllocator::Allocate
SwapIn 0,0,vmpsCode
$ vp0=>>0, valid=1, R=0, M=0, status=1, swap-1
$ vp1=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp3=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp4=>>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>>0, valid=0, R=0, M=0, status=4, swap-1
```

```
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 0, size 4
```

```
    Translate 0 , read
```

```
phys addr = 0
```

```
    value read = 201326688
```

```
Reading VA 4, size 4
```

```
    Translate 4 , read
```

```
phys addr = 4
```

```
    value read = 0
```

```
Reading VA 384, size 4
```

```
    Translate 384 , read
```

```
Invalid virtual page # 384
```

```
Received Exception 2 type: 0
```

```
EnsureIn 3
```

```
MRAllocator::Allocate
```

```
SwapIn 3,1,vmpsCode
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=0, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 384, size 4
```

```
    Translate 384 , read
```

```
phys addr = 128
```

value read = 666763232  
Reading VA 388, size 4  
Translate 388 , read  
phys addr = 132  
value read = -1346437096  
Writing VA 2024, size 4, value 8  
Translate 2024 , write  
Invalid virtual page # 2024  
Received Exception 2 type: 0

EnsureIn 15

MRAllocator::Allocate

SwapIn 15,2,vmpsStack

\$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1  
\$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp2=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1  
\$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1  
\$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp15=>2, valid=1, R=0, M=0, status=5, swap-1  
\$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

Reading VA 388, size 4

Translate 388 , read

phys addr = 132

value read = -1346437096

Writing VA 2024, size 4, value 8

Translate 2024 , write

phys addr = 360

Reading VA 392, size 4

Translate 392 , read

phys addr = 136

value read = -1347354604

Writing VA 2020, size 4, value 0

Translate 2020 , write

phys addr = 356

Reading VA 396, size 4

Translate 396 , read

phys addr = 140

value read = 201326684

Reading VA 400, size 4

Translate 400 , read

```
phys addr = 144
  value read = -1347420144
Writing VA 2016, size 4, value 0
  Translate 2016 , write
phys addr = 352
Reading VA 368, size 4
  Translate 368 , read
Invalid virtual page # 368
Received Exception 2 type: 0
```

EnsureIn 2

MRAllocator::Allocate

SwapIn 2,3,vmpsCode

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=0, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>0, valid=0, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 368, size 4

Translate 368 , read

phys addr = 496

value read = 65011720

Reading VA 372, size 4

Translate 372 , read

phys addr = 500

value read = 0

Reading VA 404, size 4

Translate 404 , read

phys addr = 148

value read = 1006895104

Reading VA 408, size 4

Translate 408 , read

phys addr = 152

value read = 612631296

Reading VA 412, size 4

Translate 412 , read

phys addr = 156

value read = 1006698496

```
Reading VA 416, size 4
  Translate 416 , read
phys addr = 160
  value read = -1407188352
Writing VA 640, size 4, value 0
  Translate 640 , write
Invalid virtual page # 640
Received Exception 2 type: 0
```

```
EnsureIn 5
```

```
MRAllocator::Allocate
```

```
SwapIn 5,4,vmpsData
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=0, M=0, status=2, swap-1
$ vp6=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 416, size 4
```

```
  Translate 416 , read
```

```
phys addr = 160
```

```
  value read = -1407188352
```

```
Writing VA 640, size 4, value 0
```

```
  Translate 640 , write
```

```
phys addr = 512
```

```
Reading VA 420, size 4
```

```
  Translate 420 , read
```

```
phys addr = 164
```

```
  value read = 1006829568
```

```
Reading VA 424, size 4
```

```
  Translate 424 , read
```

```
phys addr = 168
```

```
  value read = -1939668352
```

```
Reading VA 640, size 4
```

```
  Translate 640 , read
```

```
phys addr = 512
```

```
  value read = 0
```

```
Reading VA 428, size 4
```

```
  Translate 428 , read
```



```
phys addr = 172
  value read = 0
Reading VA 432, size 4
  Translate 432 , read
phys addr = 176
  value read = 200832
Reading VA 436, size 4
  Translate 436 , read
phys addr = 180
  value read = 4460577
Reading VA 440, size 4
  Translate 440 , read
phys addr = 184
  value read = -1404895232
Writing VA 768, size 4, value 0
  Translate 768 , write
Invalid virtual page # 768
Received Exception 2 type: 768
```

EnsureIn 6

MRAllocator::Allocate

SwapIn 6,5,vmpsDataUninit

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=0, M=0, status=4, swap-1
$ vp7=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

Reading VA 440, size 4

Translate 440 , read

phys addr = 184

value read = -1404895232

Writing VA 768, size 4, value 0

Translate 768 , write

phys addr = 640

Reading VA 444, size 4

Translate 444 , read

phys addr = 188

value read = 610467860

Reading VA 448, size 4  
  Translate 448 , read  
phys addr = 192  
  value read = 1006698496  
Reading VA 452, size 4  
  Translate 452 , read  
phys addr = 196  
  value read = -1406991744  
Writing VA 640, size 4, value 20  
  Translate 640 , write  
phys addr = 512  
Reading VA 456, size 4  
  Translate 456 , read  
phys addr = 200  
  value read = 677576804  
Reading VA 460, size 4  
  Translate 460 , read  
phys addr = 204  
  value read = 341901301  
Reading VA 464, size 4  
  Translate 464 , read  
phys addr = 208  
  value read = 605093923  
Reading VA 420, size 4  
  Translate 420 , read  
phys addr = 164  
  value read = 1006829568  
Reading VA 424, size 4  
  Translate 424 , read  
phys addr = 168  
  value read = -1939668352  
Reading VA 640, size 4  
  Translate 640 , read  
phys addr = 512  
  value read = 20  
Reading VA 428, size 4  
  Translate 428 , read  
phys addr = 172  
  value read = 0  
Reading VA 432, size 4  
  Translate 432 , read  
phys addr = 176  
  value read = 200832  
Reading VA 436, size 4  
  Translate 436 , read  
phys addr = 180  
  value read = 4460577  
Reading VA 440, size 4  
  Translate 440 , read  
phys addr = 184  
  value read = -1404895232  
Writing VA 848, size 4, value 20  
  Translate 848 , write  
phys addr = 720  
Reading VA 444, size 4  
  Translate 444 , read  
phys addr = 188

```
    value read = 610467860
Reading VA 448, size 4
    Translate 448 , read
phys addr = 192
    value read = 1006698496
Reading VA 452, size 4
    Translate 452 , read
phys addr = 196
    value read = -1406991744
Writing VA 640, size 4, value 40
    Translate 640 , write
phys addr = 512
Reading VA 456, size 4
    Translate 456 , read
phys addr = 200
    value read = 677576804
Reading VA 460, size 4
    Translate 460 , read
phys addr = 204
    value read = 341901301
Reading VA 464, size 4
    Translate 464 , read
phys addr = 208
    value read = 605093923
Reading VA 420, size 4
    Translate 420 , read
phys addr = 164
    value read = 1006829568
Reading VA 424, size 4
    Translate 424 , read
phys addr = 168
    value read = -1939668352
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 40
Reading VA 428, size 4
    Translate 428 , read
phys addr = 172
    value read = 0
Reading VA 432, size 4
    Translate 432 , read
phys addr = 176
    value read = 200832
Reading VA 436, size 4
    Translate 436 , read
phys addr = 180
    value read = 4460577
Reading VA 440, size 4
    Translate 440 , read
phys addr = 184
    value read = -1404895232
Writing VA 928, size 4, value 40
    Translate 928 , write
Invalid virtual page # 928
Received Exception 2 type: 928
```

```
EnsureIn 7
MRAllocator::Allocate
SwapIn 7,6,vmpsDataUninit
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=1, R=0, M=0, status=4, swap-1
$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
Reading VA 440, size 4
    Translate 440 , read
phys addr = 184
    value read = -1404895232
Writing VA 928, size 4, value 40
    Translate 928 , write
phys addr = 800
Reading VA 444, size 4
    Translate 444 , read
phys addr = 188
    value read = 610467860
Reading VA 448, size 4
    Translate 448 , read
phys addr = 192
    value read = 1006698496
Reading VA 452, size 4
    Translate 452 , read
phys addr = 196
    value read = -1406991744
Writing VA 640, size 4, value 60
    Translate 640 , write
phys addr = 512
Reading VA 456, size 4
    Translate 456 , read
phys addr = 200
    value read = 677576804
Reading VA 460, size 4
    Translate 460 , read
phys addr = 204
    value read = 341901301
```

```
Reading VA 464, size 4
  Translate 464 , read
phys addr = 208
  value read = 605093923
Reading VA 420, size 4
  Translate 420 , read
phys addr = 164
  value read = 1006829568
Reading VA 424, size 4
  Translate 424 , read
phys addr = 168
  value read = -1939668352
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 60
Reading VA 428, size 4
  Translate 428 , read
phys addr = 172
  value read = 0
Reading VA 432, size 4
  Translate 432 , read
phys addr = 176
  value read = 200832
Reading VA 436, size 4
  Translate 436 , read
phys addr = 180
  value read = 4460577
Reading VA 440, size 4
  Translate 440 , read
phys addr = 184
  value read = -1404895232
Writing VA 1008, size 4, value 60
  Translate 1008 , write
phys addr = 880
Reading VA 444, size 4
  Translate 444 , read
phys addr = 188
  value read = 610467860
Reading VA 448, size 4
  Translate 448 , read
phys addr = 192
  value read = 1006698496
Reading VA 452, size 4
  Translate 452 , read
phys addr = 196
  value read = -1406991744
Writing VA 640, size 4, value 80
  Translate 640 , write
phys addr = 512
Reading VA 456, size 4
  Translate 456 , read
phys addr = 200
  value read = 677576804
Reading VA 460, size 4
  Translate 460 , read
phys addr = 204
```

```
    value read = 341901301
Reading VA 464, size 4
    Translate 464 , read
phys addr = 208
    value read = 605093923
Reading VA 420, size 4
    Translate 420 , read
phys addr = 164
    value read = 1006829568
Reading VA 424, size 4
    Translate 424 , read
phys addr = 168
    value read = -1939668352
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 80
Reading VA 428, size 4
    Translate 428 , read
phys addr = 172
    value read = 0
Reading VA 432, size 4
    Translate 432 , read
phys addr = 176
    value read = 200832
Reading VA 436, size 4
    Translate 436 , read
phys addr = 180
    value read = 4460577
Reading VA 440, size 4
```

```
    Translate 440 , read

phys addr = 184
```

```
    value read = -1404895232

Writing VA 1088, size 4, value 80
```

```
    Translate 1088 , write

Invalid virtual page # 1088

Received Exception 2 type: 1088
```

```
EnsureIn 8
```

```
MRAllocator::Allocate
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
```

```
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
```

\$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1  
\$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1  
\$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1  
\$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1  
\$ vp7=>6, valid=1, R=1, M=1, status=4, swap-1  
\$ vp8=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1  
\$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

SwapOut 7

7 saved to swapPage0

换出到交换文件

SwapIn 8,6,vmpsDataUninit

\$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1  
\$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1  
\$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1  
\$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1  
\$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1  
\$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1  
\$ vp7=>6, valid=0, R=1, M=1, status=7, swap0  
\$ vp8=>6, valid=1, R=0, M=0, status=4, swap-1  
\$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1  
\$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1  
\$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1  
\$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

Reading VA 440, size 4

Translate 440 , read



```
phys addr = 184
    value read = -1404895232
Writing VA 1088, size 4, value 80
    Translate 1088 , write
phys addr = 832
Reading VA 444, size 4
    Translate 444 , read
phys addr = 188
    value read = 610467860
Reading VA 448, size 4
    Translate 448 , read
phys addr = 192
    value read = 1006698496
Reading VA 452, size 4
    Translate 452 , read
phys addr = 196
    value read = -1406991744
Writing VA 640, size 4, value 100
    Translate 640 , write
phys addr = 512
Reading VA 456, size 4
    Translate 456 , read
phys addr = 200
    value read = 677576804
Reading VA 460, size 4
    Translate 460 , read
phys addr = 204
    value read = 341901301
Reading VA 464, size 4
    Translate 464 , read
phys addr = 208
    value read = 605093923
Reading VA 468, size 4
    Translate 468 , read
phys addr = 212
    value read = 1006698496
Reading VA 472, size 4
    Translate 472 , read
phys addr = 216
    value read = -1407188352
Writing VA 640, size 4, value 0
    Translate 640 , write
phys addr = 512
Reading VA 476, size 4
    Translate 476 , read
phys addr = 220
    value read = 1007681536
Reading VA 480, size 4
    Translate 480 , read
phys addr = 224
    value read = 638583552
```

```
Reading VA 484, size 4
  Translate 484 , read
phys addr = 228
  value read = 1006960640
Reading VA 488, size 4
  Translate 488 , read
phys addr = 232
  value read = -1935342976
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 0
Reading VA 492, size 4
  Translate 492 , read
phys addr = 236
  value read = 0
Reading VA 496, size 4
  Translate 496 , read
phys addr = 240
  value read = 331904
Reading VA 500, size 4
  Translate 500 , read
phys addr = 244
  value read = 5247009
VirtMemMRAllocator::TimerCallback 0
Reading VA 504, size 4
  Translate 504 , read
phys addr = 248
  value read = 337984
Reading VA 508, size 4
  Translate 508 , read
phys addr = 252
  value read = -1941700608
Reading VA 768, size 4
  Translate 768 , read
phys addr = 640
  value read = 0
Reading VA 512, size 4
  Translate 512 , read
Invalid virtual page # 512
Received Exception 2 type: 768
```

EnsureIn 4

```
MRAllocator::Allocate
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=0, R=1, M=1, status=7, swap0
$ vp8=>6, valid=1, R=1, M=1, status=4, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
```

```
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 8
```

```
8 saved to swapPage1
```

```
SwapIn 4,6,vmpsCode
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>6, valid=1, R=0, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=0, R=1, M=1, status=7, swap0
$ vp8=>6, valid=0, R=1, M=1, status=7, swap1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 512, size 4
```

```
Translate 512 , read
```

```
phys addr = 768
```

```
value read = 201326600
```

```
Reading VA 516, size 4
```

```
Translate 516 , read
```

```
phys addr = 772
```

```
value read = 35989539
```

```
Reading VA 32, size 4
```

```
Translate 32 , read
```

```
phys addr = 32
```

```
value read = 604110890
```

```
Reading VA 36, size 4
```

```
Translate 36 , read
```

```
phys addr = 36
```

```
value read = 12
```

```
Received Exception 1 type: 42
```

```
Add 0 + 35
```

```
Add returning with 35

Reading VA 40, size 4
  Translate 40 , read
phys addr = 40
  value read = 65011720
Reading VA 44, size 4
  Translate 44 , read
phys addr = 44
  value read = 0
Reading VA 520, size 4
  Translate 520 , read
phys addr = 776
  value read = 1006895104
Reading VA 524, size 4
  Translate 524 , read
phys addr = 780
  value read = -1937505664
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 0
Reading VA 528, size 4
  Translate 528 , read
phys addr = 784
  value read = 0
Reading VA 532, size 4
  Translate 532 , read
phys addr = 788
  value read = 612564993
Reading VA 536, size 4
  Translate 536 , read
phys addr = 792
  value read = 202880
Reading VA 540, size 4
  Translate 540 , read
phys addr = 796
  value read = 7346209
Reading VA 544, size 4
  Translate 544 , read
phys addr = 800
  value read = 612630548
Reading VA 548, size 4
  Translate 548 , read
phys addr = 804
  value read = -1402863616
Writing VA 772, size 4, value 35
  Translate 772 , write
phys addr = 644
Reading VA 552, size 4
  Translate 552 , read
phys addr = 808
  value read = 1006698496
Reading VA 556, size 4
  Translate 556 , read
phys addr = 812
```

```
    value read = -1406926208
Writing VA 640, size 4, value 20
    Translate 640 , write
phys addr = 512
Reading VA 560, size 4
    Translate 560 , read
phys addr = 816
    value read = 679739492
Reading VA 564, size 4
    Translate 564 , read
phys addr = 820
    value read = 343998443
Reading VA 568, size 4
    Translate 568 , read
phys addr = 824
    value read = 0
Reading VA 484, size 4
    Translate 484 , read
phys addr = 228
    value read = 1006960640
Reading VA 488, size 4
    Translate 488 , read
phys addr = 232
    value read = -1935342976
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 20
Reading VA 492, size 4
    Translate 492 , read
phys addr = 236
    value read = 0
Reading VA 496, size 4
    Translate 496 , read
phys addr = 240
    value read = 331904
Reading VA 500, size 4
    Translate 500 , read
phys addr = 244
    value read = 5247009
Reading VA 504, size 4
    Translate 504 , read
phys addr = 248
    value read = 337984
Reading VA 508, size 4
    Translate 508 , read
phys addr = 252
    value read = -1941700608
Reading VA 848, size 4
    Translate 848 , read
phys addr = 720
    value read = 20
Reading VA 512, size 4
    Translate 512 , read
phys addr = 768
    value read = 201326600
Reading VA 516, size 4
```

```
Translate 516 , read
phys addr = 772
value read = 35989539
Reading VA 32, size 4
Translate 32 , read
phys addr = 32
value read = 604110890
Reading VA 36, size 4
Translate 36 , read
phys addr = 36
value read = 12
Received Exception 1 type: 42
```

Add 20 + -5

Add returning with 15

```
Reading VA 40, size 4
Translate 40 , read
phys addr = 40
value read = 65011720
Reading VA 44, size 4
Translate 44 , read
phys addr = 44
value read = 0
Reading VA 520, size 4
Translate 520 , read
phys addr = 776
value read = 1006895104
Reading VA 524, size 4
Translate 524 , read
phys addr = 780
value read = -1937505664
Reading VA 640, size 4
Translate 640 , read
phys addr = 512
value read = 20
Reading VA 528, size 4
Translate 528 , read
phys addr = 784
value read = 0
Reading VA 532, size 4
Translate 532 , read
phys addr = 788
value read = 612564993
Reading VA 536, size 4
Translate 536 , read
phys addr = 792
value read = 202880
Reading VA 540, size 4
Translate 540 , read
phys addr = 796
value read = 7346209
Reading VA 544, size 4
Translate 544 , read
phys addr = 800
value read = 612630548
```

Reading VA 548, size 4  
  Translate 548 , read  
phys addr = 804  
  value read = -1402863616  
Writing VA 852, size 4, value 15  
  Translate 852 , write  
phys addr = 724  
Reading VA 552, size 4  
  Translate 552 , read  
phys addr = 808  
  value read = 1006698496  
Reading VA 556, size 4  
  Translate 556 , read  
phys addr = 812  
  value read = -1406926208  
Writing VA 640, size 4, value 40  
  Translate 640 , write  
phys addr = 512  
Reading VA 560, size 4  
  Translate 560 , read  
phys addr = 816  
  value read = 679739492  
Reading VA 564, size 4  
  Translate 564 , read  
phys addr = 820  
  value read = 343998443  
Reading VA 568, size 4  
  Translate 568 , read  
phys addr = 824  
  value read = 0  
Reading VA 484, size 4  
  Translate 484 , read  
phys addr = 228  
  value read = 1006960640  
Reading VA 488, size 4  
  Translate 488 , read  
phys addr = 232  
  value read = -1935342976  
Reading VA 640, size 4  
  Translate 640 , read  
phys addr = 512  
  value read = 40  
Reading VA 492, size 4  
  Translate 492 , read  
phys addr = 236  
  value read = 0  
Reading VA 496, size 4  
  Translate 496 , read  
phys addr = 240  
  value read = 331904  
Reading VA 500, size 4  
  Translate 500 , read  
phys addr = 244  
  value read = 5247009  
Reading VA 504, size 4  
  Translate 504 , read  
phys addr = 248

```
value read = 337984
Reading VA 508, size 4
Translate 508 , read
phys addr = 252
value read = -1941700608
Reading VA 928, size 4
Translate 928 , read
Invalid virtual page # 928
Received Exception 2 type: 928
```

EnsureIn 7

MRAllocator::Allocate

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>6, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>6, valid=0, R=1, M=1, status=7, swap0
$ vp8=>6, valid=0, R=1, M=1, status=7, swap1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=1, R=1, M=1, status=5, swap-1
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 15
```

15 saved to swapPage2

SwapIn 7,2,vmpsSwap

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>6, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>2, valid=1, R=0, M=0, status=7, swap-1
$ vp8=>6, valid=0, R=1, M=1, status=7, swap1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=0, R=1, M=1, status=7, swap2
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
```



\$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1  
\$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1

Reading VA 508, size 4

Translate 508 , read

phys addr = 252

value read = -1941700608

Reading VA 928, size 4

Translate 928 , read

phys addr = 288

value read = 40

Reading VA 512, size 4

Translate 512 , read

phys addr = 768

value read = 201326600

Reading VA 516, size 4

Translate 516 , read

phys addr = 772

value read = 35989539

Reading VA 32, size 4

Translate 32 , read

phys addr = 32

value read = 604110890

Reading VA 36, size 4

Translate 36 , read

phys addr = 36

value read = 12

Received Exception 1 type: 42

Add 40 + -45

Add returning with -5

Reading VA 40, size 4

Translate 40 , read

phys addr = 40

value read = 65011720

Reading VA 44, size 4

Translate 44 , read

phys addr = 44

value read = 0

Reading VA 520, size 4

Translate 520 , read

phys addr = 776

value read = 1006895104

Reading VA 524, size 4

Translate 524 , read

phys addr = 780

value read = -1937505664

Reading VA 640, size 4

Translate 640 , read

phys addr = 512

value read = 40

Reading VA 528, size 4

```
Translate 528 , read
phys addr = 784
value read = 0
Reading VA 532, size 4
Translate 532 , read
phys addr = 788
value read = 612564993
Reading VA 536, size 4
Translate 536 , read
phys addr = 792
value read = 202880
Reading VA 540, size 4
Translate 540 , read
phys addr = 796
value read = 7346209
Reading VA 544, size 4
Translate 544 , read
phys addr = 800
value read = 612630548
Reading VA 548, size 4
Translate 548 , read
phys addr = 804
value read = -1402863616
Writing VA 932, size 4, value -5
Translate 932 , write
phys addr = 292
Reading VA 552, size 4
Translate 552 , read
phys addr = 808
value read = 1006698496
Reading VA 556, size 4
Translate 556 , read
phys addr = 812
value read = -1406926208
Writing VA 640, size 4, value 60
Translate 640 , write
phys addr = 512
Reading VA 560, size 4
Translate 560 , read
phys addr = 816
value read = 679739492
Reading VA 564, size 4
Translate 564 , read
phys addr = 820
value read = 343998443
Reading VA 568, size 4
Translate 568 , read
phys addr = 824
value read = 0
Reading VA 484, size 4
Translate 484 , read
phys addr = 228
value read = 1006960640
Reading VA 488, size 4
Translate 488 , read
phys addr = 232
value read = -1935342976
```

```
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 60
Reading VA 492, size 4
  Translate 492 , read
phys addr = 236
  value read = 0
Reading VA 496, size 4
  Translate 496 , read
phys addr = 240
  value read = 331904
Reading VA 500, size 4
  Translate 500 , read
phys addr = 244
  value read = 5247009
VirtMemMRAllocator::TimerCallback 1
Reading VA 504, size 4
  Translate 504 , read
phys addr = 248
  value read = 337984
Reading VA 508, size 4
  Translate 508 , read
phys addr = 252
  value read = -1941700608
Reading VA 1008, size 4
  Translate 1008 , read
phys addr = 368
  value read = 60
Reading VA 512, size 4
  Translate 512 , read
phys addr = 768
  value read = 201326600
Reading VA 516, size 4
  Translate 516 , read
phys addr = 772
  value read = 35989539
Reading VA 32, size 4
  Translate 32 , read
phys addr = 32
  value read = 604110890
Reading VA 36, size 4
  Translate 36 , read
phys addr = 36
  value read = 12
Received Exception 1 type: 42
```

Add 60 + -85

Add returning with -25

```
Reading VA 40, size 4
  Translate 40 , read
phys addr = 40
  value read = 65011720
Reading VA 44, size 4
  Translate 44 , read
```

```
phys addr = 44
  value read = 0
Reading VA 520, size 4
  Translate 520 , read
phys addr = 776
  value read = 1006895104
Reading VA 524, size 4
  Translate 524 , read
phys addr = 780
  value read = -1937505664
Reading VA 640, size 4
  Translate 640 , read
phys addr = 512
  value read = 60
Reading VA 528, size 4
  Translate 528 , read
phys addr = 784
  value read = 0
Reading VA 532, size 4
  Translate 532 , read
phys addr = 788
  value read = 612564993
Reading VA 536, size 4
  Translate 536 , read
phys addr = 792
  value read = 202880
Reading VA 540, size 4
  Translate 540 , read
phys addr = 796
  value read = 7346209
Reading VA 544, size 4
  Translate 544 , read
phys addr = 800
  value read = 612630548
Reading VA 548, size 4
  Translate 548 , read
phys addr = 804
  value read = -1402863616
Writing VA 1012, size 4, value -25
  Translate 1012 , write
phys addr = 372
Reading VA 552, size 4
  Translate 552 , read
phys addr = 808
  value read = 1006698496
Reading VA 556, size 4
  Translate 556 , read
phys addr = 812
  value read = -1406926208
Writing VA 640, size 4, value 80
  Translate 640 , write
phys addr = 512
Reading VA 560, size 4
  Translate 560 , read
phys addr = 816
  value read = 679739492
Reading VA 564, size 4
```

```
Translate 564 , read
phys addr = 820
value read = 343998443
Reading VA 568, size 4
Translate 568 , read
phys addr = 824
value read = 0
Reading VA 484, size 4
Translate 484 , read
phys addr = 228
value read = 1006960640
Reading VA 488, size 4
Translate 488 , read
phys addr = 232
value read = -1935342976
Reading VA 640, size 4
Translate 640 , read
phys addr = 512
value read = 80
Reading VA 492, size 4
Translate 492 , read
phys addr = 236
value read = 0
Reading VA 496, size 4
Translate 496 , read
phys addr = 240
value read = 331904
Reading VA 500, size 4
Translate 500 , read
phys addr = 244
value read = 5247009
Reading VA 504, size 4
Translate 504 , read
phys addr = 248
value read = 337984
Reading VA 508, size 4
Translate 508 , read
phys addr = 252
value read = -1941700608
Reading VA 1088, size 4
Translate 1088 , read
Invalid virtual page # 1088
Received Exception 2 type: 1088
```

EnsureIn 8

```
MRAllocator::Allocate
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>6, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>2, valid=1, R=1, M=1, status=7, swap-1
$ vp8=>6, valid=0, R=1, M=1, status=7, swap1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
```

```
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=0, R=1, M=1, status=7, swap2
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
SwapOut 7
```

```
7 saved to swapPage0
```

```
SwapIn 8,2,vmpsSwap
```

```
$ vp0=>0, valid=1, R=1, M=0, status=1, swap-1
$ vp1=>0, valid=0, R=0, M=0, status=1, swap-1
$ vp2=>3, valid=1, R=1, M=0, status=1, swap-1
$ vp3=>1, valid=1, R=1, M=0, status=1, swap-1
$ vp4=>6, valid=1, R=1, M=0, status=1, swap-1
$ vp5=>4, valid=1, R=1, M=1, status=2, swap-1
$ vp6=>5, valid=1, R=1, M=1, status=4, swap-1
$ vp7=>2, valid=0, R=1, M=1, status=7, swap0
$ vp8=>2, valid=1, R=0, M=0, status=7, swap-1
$ vp9=>0, valid=0, R=0, M=0, status=4, swap-1
$ vp10=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp11=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp12=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp13=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp14=>0, valid=0, R=0, M=0, status=5, swap-1
$ vp15=>2, valid=0, R=1, M=1, status=7, swap2
$ vp16=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp17=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp18=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp19=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp20=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp21=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp22=>0, valid=0, R=0, M=0, status=0, swap-1
$ vp23=>0, valid=0, R=0, M=0, status=0, swap-1
```

```
Reading VA 508, size 4
```

```
Translate 508 , read
```

```
phys addr = 252
```

```
value read = -1941700608
```

```
Reading VA 1088, size 4
```

```
Translate 1088 , read
```

```
phys addr = 320
```

```
value read = 80
```

```
Reading VA 512, size 4
```

```
Translate 512 , read
```

```
phys addr = 768
```

```
value read = 201326600
```

```
Reading VA 516, size 4
```

```
Translate 516 , read
```

```
phys addr = 772
```

```
value read = 35989539
```

```
Reading VA 32, size 4
```

```
    Translate 32 , read
phys addr = 32
    value read = 604110890
Reading VA 36, size 4
    Translate 36 , read
phys addr = 36
    value read = 12
Received Exception 1 type: 42

Add 80 + -125

Add returning with -45

Reading VA 40, size 4
    Translate 40 , read
phys addr = 40
    value read = 65011720
Reading VA 44, size 4
    Translate 44 , read
phys addr = 44
    value read = 0
Reading VA 520, size 4
    Translate 520 , read
phys addr = 776
    value read = 1006895104
Reading VA 524, size 4
    Translate 524 , read
phys addr = 780
    value read = -1937505664
Reading VA 640, size 4
    Translate 640 , read
phys addr = 512
    value read = 80
Reading VA 528, size 4
    Translate 528 , read
phys addr = 784
    value read = 0
Reading VA 532, size 4
    Translate 532 , read
phys addr = 788
    value read = 612564993
Reading VA 536, size 4
    Translate 536 , read
phys addr = 792
    value read = 202880
Reading VA 540, size 4
    Translate 540 , read
phys addr = 796
    value read = 7346209
Reading VA 544, size 4
    Translate 544 , read
phys addr = 800
    value read = 612630548
Reading VA 548, size 4
    Translate 548 , read
phys addr = 804
    value read = -1402863616
```

```
Writing VA 1092, size 4, value -45
  Translate 1092 , write
phys addr = 324
Reading VA 552, size 4
  Translate 552 , read
phys addr = 808
  value read = 1006698496
Reading VA 556, size 4
  Translate 556 , read
phys addr = 812
  value read = -1406926208
Writing VA 640, size 4, value 100
  Translate 640 , write
phys addr = 512
Reading VA 560, size 4
  Translate 560 , read
phys addr = 816
  value read = 679739492
Reading VA 564, size 4
  Translate 564 , read
phys addr = 820
  value read = 343998443
Reading VA 568, size 4
  Translate 568 , read
phys addr = 824
  value read = 0
Reading VA 572, size 4
  Translate 572 , read
phys addr = 828
  value read = 201326596
Reading VA 576, size 4
  Translate 576 , read
phys addr = 832
  value read = 0
Reading VA 16, size 4
  Translate 16 , read
phys addr = 16
  value read = 604110848
Reading VA 20, size 4
  Translate 20 , read
phys addr = 20
  value read = 12
Received Exception 1 type: 0
```

Shutdown, initiated by user program.

Machine halting!

Ticks: total 261, idle 0, system 40, user 221

Disk I/O: reads 0, writes 0

Console I/O: reads 0, writes 0

Paging: faults 11



```
Network I/O: packets received 0, sent 0
```

## 七、开发小结

- 有了上次的经验，这次做得很快
- 在不知从何入手的时候，可以先写出一个个与实验目标有关的功能块（例如 Allocator、SwapOut、SwapIn），然后把它们组合起来

## 八、参考资料

1. [A Road Map Through Nachos](#) 概要性介绍了Nachos源码的各个部分：机器、线程、用户进程、文件系统.....