The Memory Manager Project

Objectives

- The goal of your next project is to simulate the C heap manager
- A runtime module used to allocate and de-allocate dynamic memory.
- The "heap" is a large "pool" of memory set aside by the runtime system
- The two main functions are
  - **`malloc`**, used to satisfy a request for a specific number of consecutive blocks;
  - **`free`**, used to make allocated blocks available f

Description

- Our simulation uses
  - a large block of unsigned chars as our memory pool; and
  - a doubly-linked list to keep track of allocated and available blocks of unsigned char.
  - We will refer to the nodes of this list as *blocknodes*
- The info field of each node is of type **`blockdata`**
- An object of type **`blockdata`** has attributes
  - **`blocksize`** number of bytes in the block
  - **`free`** a Boolean flag indicating the status of a block
  - **`blockptr`** a pointer to the first byte of the block

malloc

- The **malloc** algorithm has an **int** parameter **request**
- **request** is the size of the block to be allocated
- **request** scans the list until it finds the first blocknode **B** such that
  - **B.free == true**
  - **B.size ≥ request**
- If no such block is found, **malloc** returns **NULL (0)**

`malloc`

- If **`B.size`** is larger than **`request`**, the block is broken up into two blocks
  - The first block's size: **`request`**
  - The second's size: **`B.size-request`**
- This requires that we insert a new blocknode **`C`** after **`B`** to reference the second block (which is free)
- Then, whether we split the block or not, we
  - set **`B.free`** to **`false`**
  - set **`B.size`** to **`request`**
  - return the address **`B.bptr`**

`free`

- To implement **`free(unsigned char *p)`** we must find the blocknode whose **`bptr`** field equals **`p`**
- This is done by traversing the blocknode list
- If this fails, we terminate the program
- Otherwise we change the blocknode's **`free`** field to **`true`**
- But we don't stop there

Merging Consecutive `free` Blocks

- It should be clear that we want to maximize the size of the free blocks
- This means there should never be consecutive free blocks
- Whenever consecutive free blocks occur, they should be merged
- When we free a block, we need to check the previous and next blocks to see if they are free
- If so, we must merge the blocks into one big block
- This may involve the deletion of one or two blocknodes from our list

Doubly-Linked List Utilities

- To manage doubly-linked lists, we will use a collection of templated functions
- We will not need the apparatus of a class here, a **`struct`** suffices
- The definition of **`dlNode`** and associated functions will be supplied in the file **`dlListUtils.h`**

Project Files

- The files used in this project are

• `dlListUtils.h`	Do not modify, do not submit
• `blockdata.h`	
• `blockdata.cpp`	
• `MemoryManager.h`	
• `MemoryManager.cpp`	Complete and submit
• `testMemMgr.cpp`	Modify and use for testing; Do not submit

Source Code

dlUtils.h

```
template <class T>
struct dlNode {
  T info;
  dlNode<T> *prev;
  dlNode<T> *next;
  dlNode<T>(T val, dlNode<T> *p,
            dlNode<T> *n)
                :info(val),prev(p),next(n){};
};
```

dlUtils.h

```
template <class T>
void insertAsFirst(dlNode<T>* &first,
                   T newval)
{
  first = new dlNode<T>(newval,NULL,first);
  first->next->prev = first;
}
```

dlUtils.h

```
template <class T>
void insertAfter(dlNode<T> *first,
                 dlNode<T> *current, T newval)

{

  assert(current != NULL);

  current->next = new
      dlNode<T>(newval,current,current->next);

  current = current->next;

  if (current->next != nullptr)
    current->next->prev = current;

}
```

dlUtils.h

```
template <class T>
void printDlList(const dlNode<T> *first,
                 const char *sep)

{

  dlNode<T> *cursor = first;

  while(cursor != nullptr &&
        cursor->next!= nullptr)
  {
    std::cout << cursor->info << sep;
    cursor = cursor->next;
  }

  if (cursor != NULL)
    std::cout << cursor->info << std::endl;
}
```

dlUtils.h

```
template <class T>
void insertBefore(dlNode<T>* &first,
                  dlNode<T> *current,
                  T newval)
{
  assert(current != NULL);
  if (current == first)
     insertAsFirst(first,newval);
  else
     insertAfter(first,current->prev,newval);
}
```

dlUtils.h

```
template <class T>
void deleteNext(dlNode<T> *current)
{
  assert(current != nullptr &&
         current->next != nullptr);

  dlNode<T> *hold = current->next;
  current->next = hold->next;

  if (current->next != nullptr)
   current->next->prev = current;

  delete hold;

}
```

dlUtils.h

```
template <class T>
void deletePrevious(dlNode<T>* &first,
                dlNode<T> *current)
{
  assert(first != nullptr && current != nullptr
         && current->prev != nullptr);

  dlNode<T> *hold = current->prev;
  current->prev = hold->prev;

  if (current->prev != nullptr)
    current->prev->next = current;
  else
    first = current;

  delete hold;

}
```

dlUtils.h

```
template <class T>
void deletePrevious(dlNode<T>* &first,
                dlNode<T> *current)
{
  assert(first != nullptr &&
         current != nullptr &&
         current->prev != nullptr);

  dlNode<T> *hold = current->prev;
  current->prev = hold->prev;

  if (current->prev != nullptr)
   current->prev->next = current;
  else void
MemoryManager::mergeForward(dlNode<blockdata>
*p)

{ // Put your code below
```

dlUtils.h

```
template <class T>

void deleteNode(dlNode<T>* &first,
                dlNode<T>* current)
{
  assert(first != nullptr &&
         current != nullptr);

  dlNode<T> *hold = current;
  if (current == first) {
    first = first->next;
    first->prev = nullptr;
    current = first;
  } else {
    current->prev->next = current->next;
    current->next->prev = current->prev;
    current = current->prev;
  }
  delete hold;
}
```

The blockdata Definition

```
// blockdata.h
#include <iostream>

class blockdata {
  friend ostream& operator<<(ostream&
                          const blockdata &);

 public:
  blockdata(int s, bool f, unsigned char *p);
  int blocksize;
  bool free;
  unsigned char *blockptr;
};
```

The `blockdata` Implementation

```cpp
// blockdata.cpp
blockdata::blockdata(int s, bool f,
                     unsigned char *p)
{
  blocksize = s;
  free = f;
  blockptr = p;
}
```

The blockdata Implementation

```
// blockdata.cpp

std::ostream &operator<<(std::ostream &out,
                         const blockdata &B)
{
  std::out << "[" << B.blocksize << ",";
  if (B.free)
    std::out << "free";
  else
    out << "allocated";
  out << "]";
  return out;
}
```

The MemoryManager Definition

```
class MemoryManager
{
  public:
   MemoryManager(unsigned int memsize);
   unsigned char *
   malloc(unsigned int request);
   // if malloc fails, it returns nullptr
   void free(unsigned char * memptr);
   void showBlockList();
  private:
   unsigned int memsize; // Heap size
   // pointer to the first heap byte of heap:
   unsigned char *baseptr;
   dlNode<blockdata> *firstBlock;
   // Utility method for free function:
   void mergeForward(dlNode<blockdata> *p);
 // Utility method for malloc function:
   void splitBlock(dlNode<blockdata> *p,
                   unsigned int chunksize);
};
```

The MemoryManager Implementation

```
#include <cassert>
#include <iostream>
#include "dlUtils.h“
#include "MemoryManager.h"

MemoryManager::MemoryManager(
     unsigned int memtotal): memsize(memtotal)
{

   baseptr = new unsigned char[memsize];

   blockdata originalBlock(memsize,true,baseptr);

   firstBlock = new dlNode<blockdata>(
                      originalBlock,nullptr,nullptr);
}
```

The MemoryManager Implementation (partial)

```
void MemoryManager::showBlockList()
{
  printDlList(firstBlock,"->");
}

void
MemoryManager::mergeForward(dlNode<blockdata> *p)

{ // Put your code here }

void
MemoryManager::free(unsigned char *ptr2block)

{// Put your code here }
```

The MemoryManager Implementation (partial)

```
void
MemoryManager::mergeForward(dlNode<blockdata> *p)

{ // Put your code here }

void
MemoryManager::free(unsigned char *ptr2block)

{ // Put your code here }
```

The MemoryManager Implementation (partial)

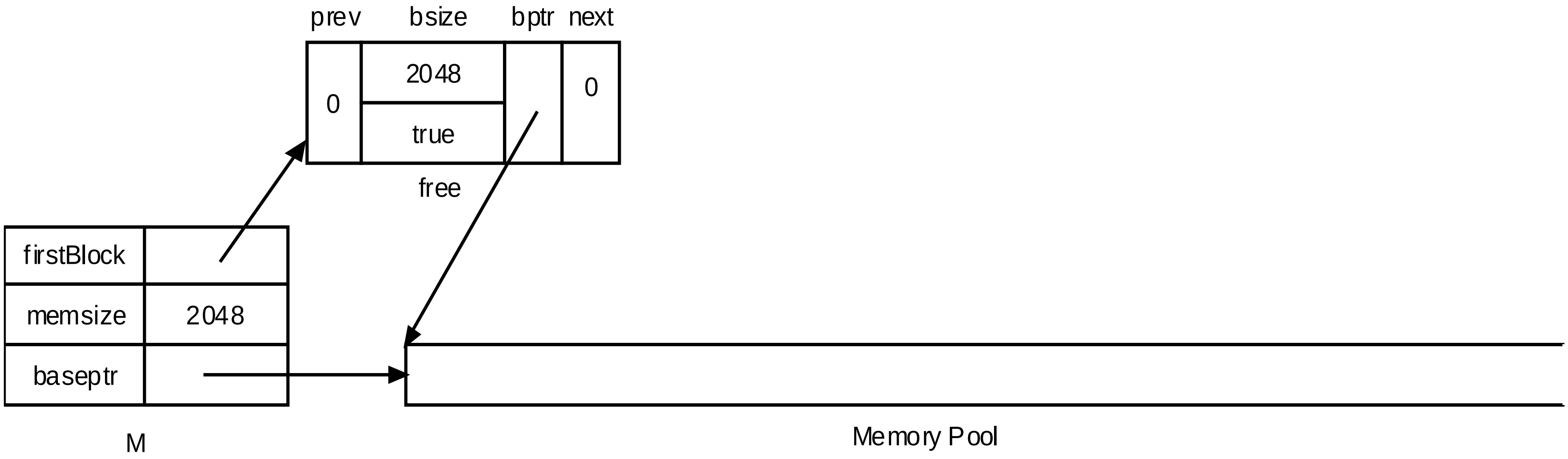
```
void
MemoryManager::splitBlock(dlNode<blockdata> *p,
                          unsigned int chunksize)
{ // Put your code here }

unsigned char *
MemoryManager::malloc(unsigned int request)
{ // Put your code here }
```

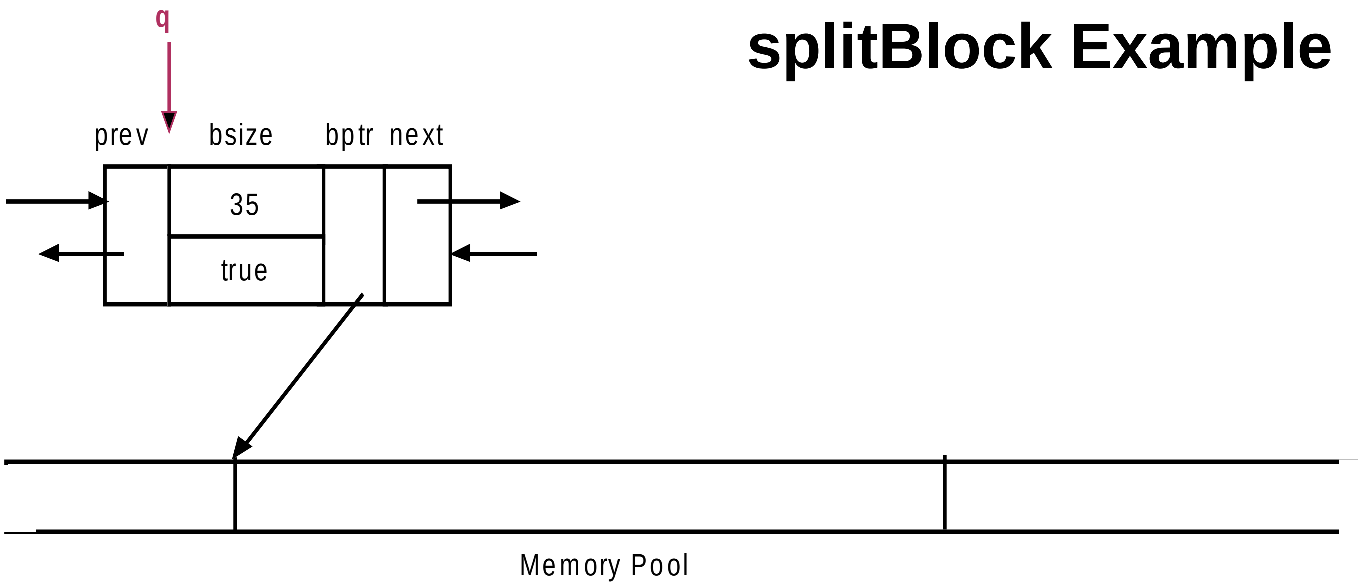
Visual Trace of Operations

The `MemoryManager` Constructor

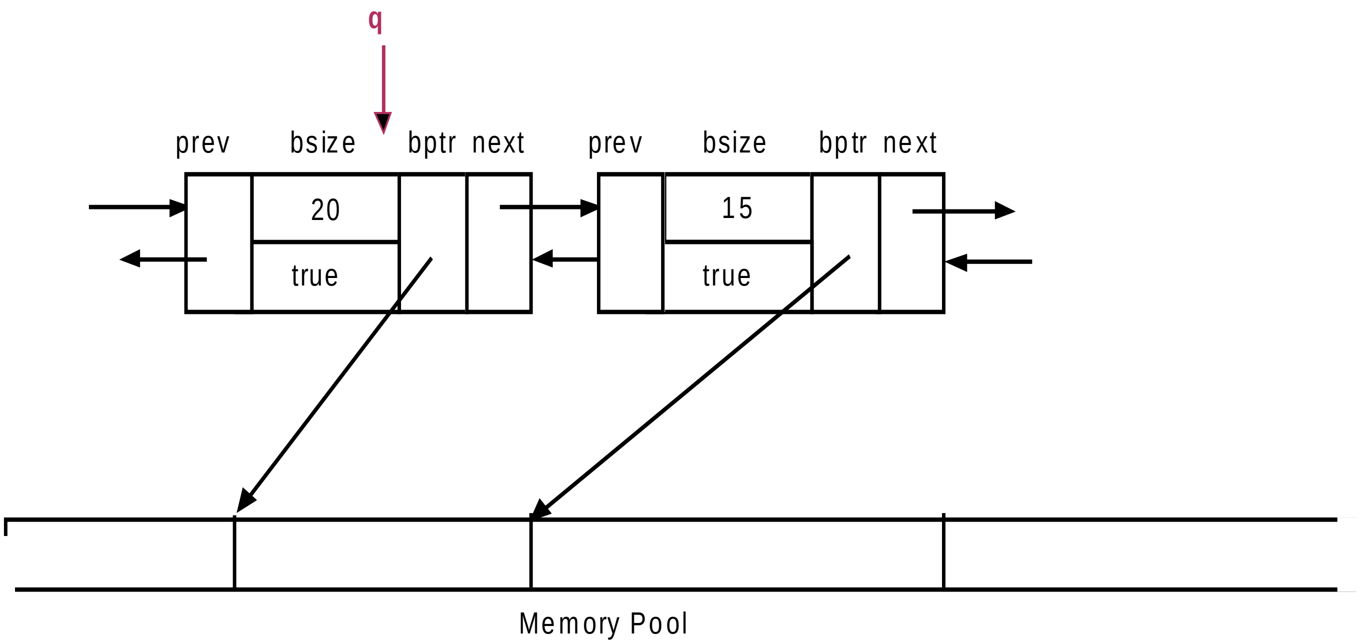
`MemoryManager M(2048);`

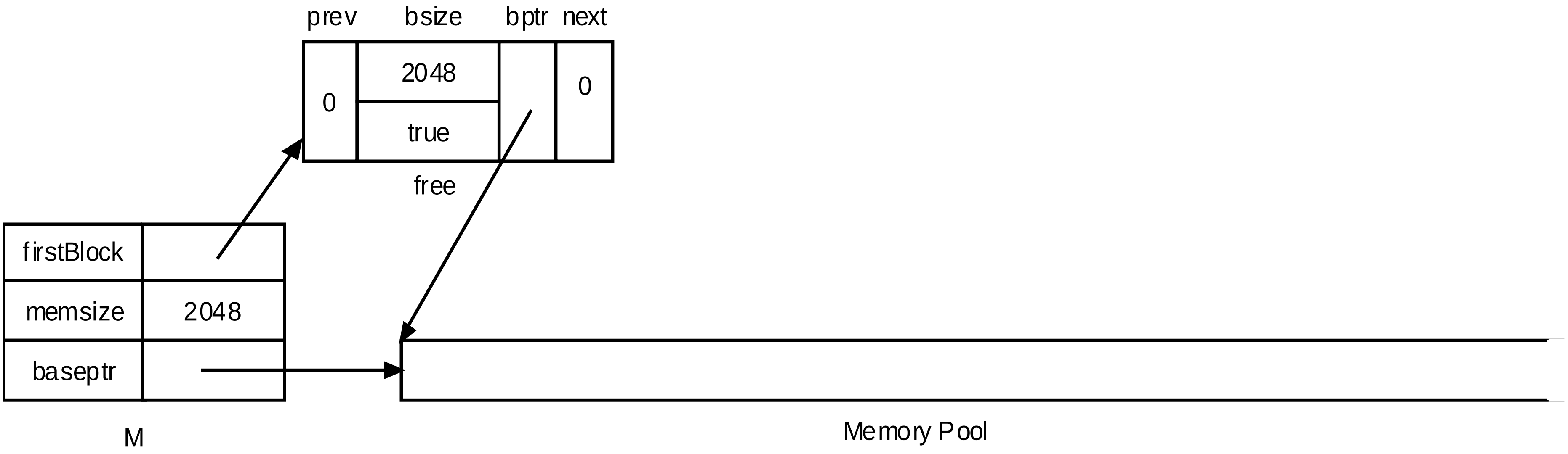


splitBlock Example

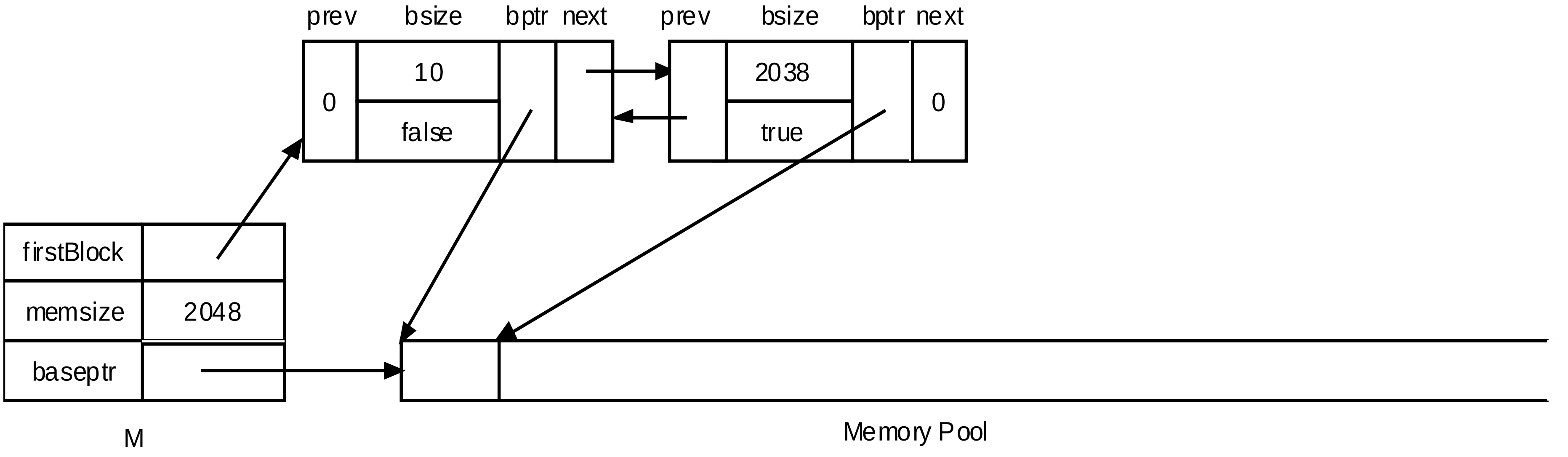


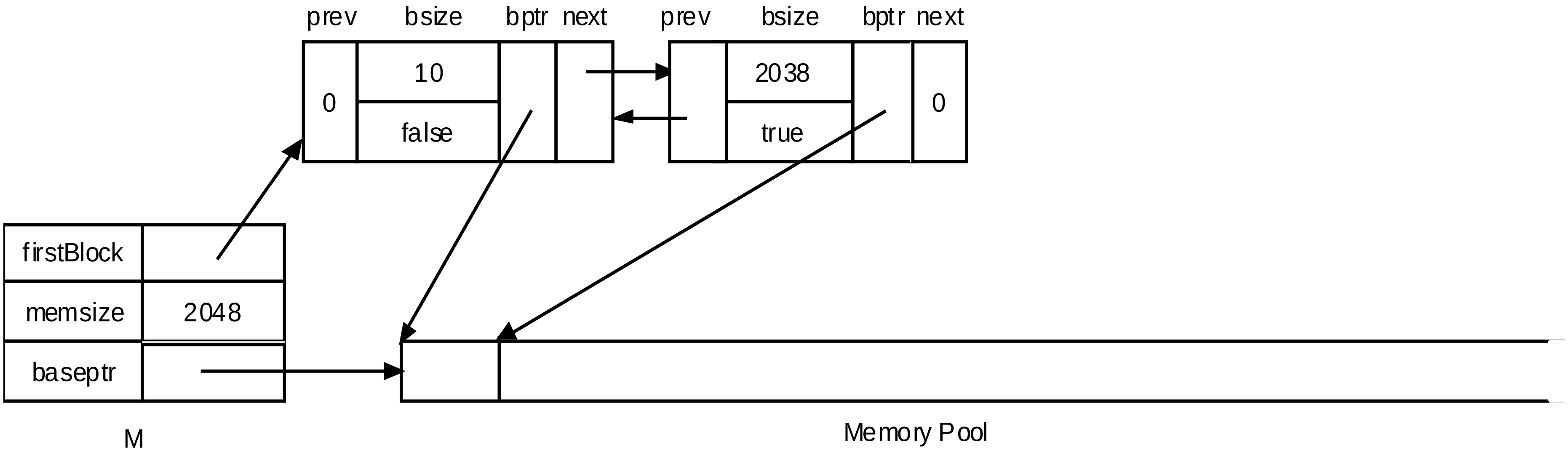
```
splitBlock(q,20);
```



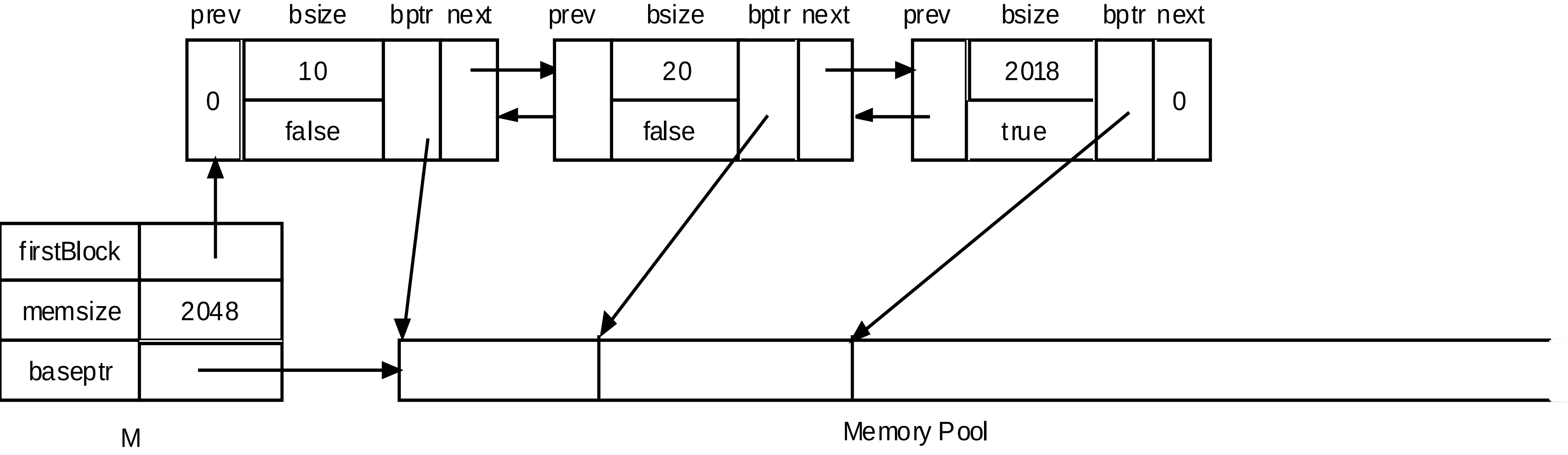


```
unsigned char *p1 = M.malloc(10);
```

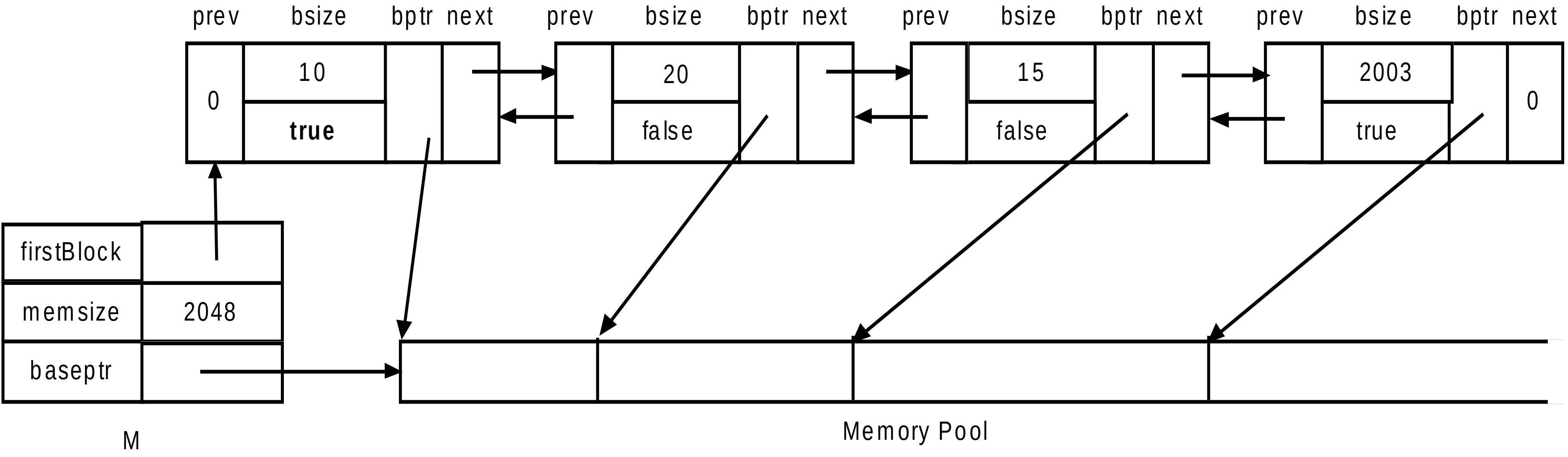




```
unsigned char *p2 = M.malloc(20);
```

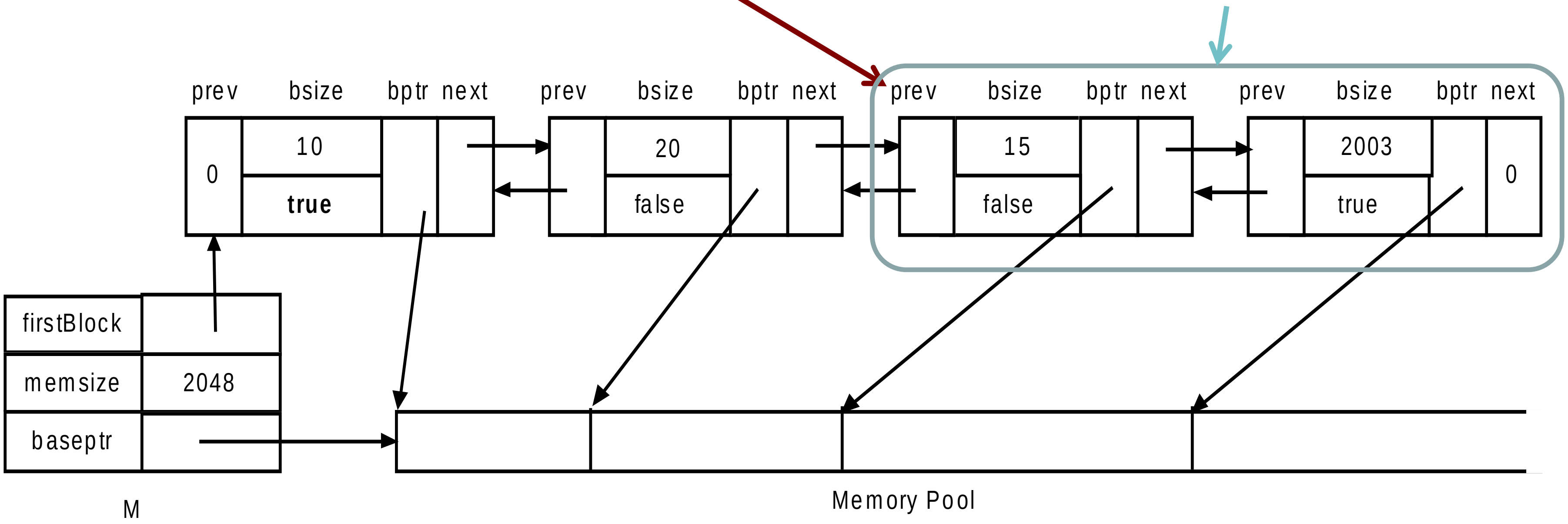


p1 = M.malloc(15);

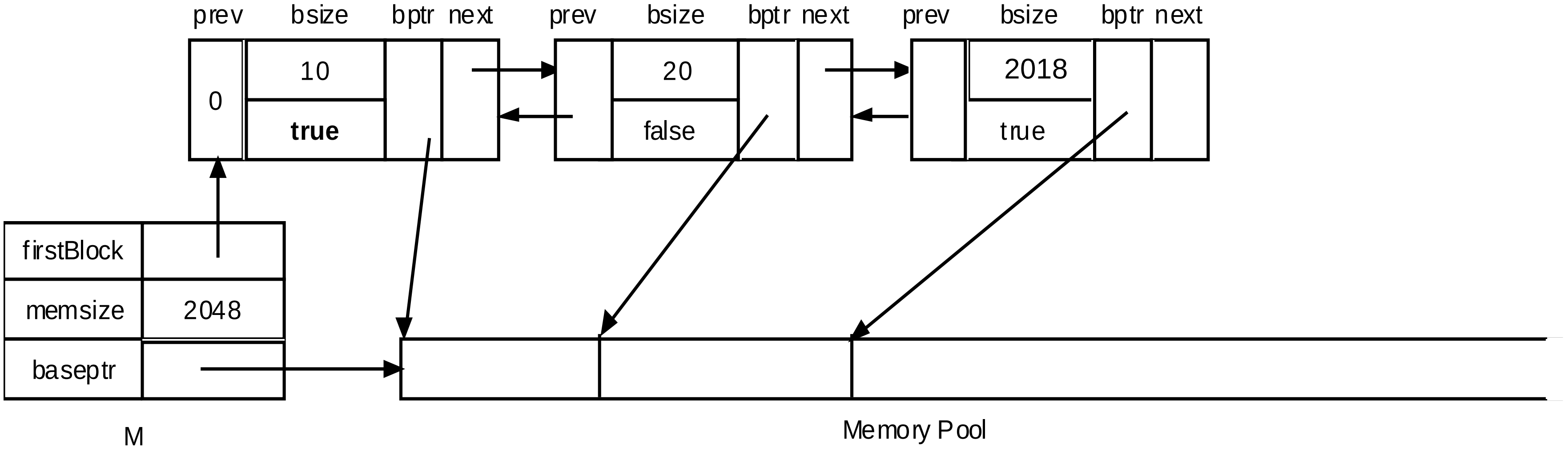


Block allocated to p1

When free is called on p1, we must merge the resulting consecutive free blocks to one



```
M.free(p1);
```



Testing Code

```
#include <iostream>
#include <cassert>
#include "MemoryManager.h"

const char * startlist =
      "\n---------BlockList start--------------\n"
const char * endlist =
      "\n---------BlockList end-------------\n"
int main()
{
   MemoryManager heaper(2048);
   cout << "heap initialized\n";

   cout << startlist;
   cout << heaper << endl;
   cout << endlist;
cout << "Doing first malloc:\n";
unsigned char * p1 = heaper.malloc(10);
cout << "malloc done\n";

cout << startlist;
cout << heaper << endl;
cout << endlist;

cout << "On to the second malloc\n";
unsigned char *p2 = heaper.malloc(20);
cout << "malloc done\n";

cout << startlist;
cout << heaper << endl;
cout << endlist;
cout << "Next free the first pointer\n";
heaper.free(p1);

cout << startlist;
cout << heaper << endl;
cout << endlist;

cout << "Now do a malloc for a block too big for "
     << "the initial open block\n";
p1 = heaper.malloc(15);
cout << "malloc done\n";

cout << startlist;
cout << heaper << endl; n\n";
cout << endlist;
```

```
   cout << "Next free the most recently "
        << "allocated pointer\n";
   heaper.free(p1);

   cout << startlist;
   cout << heaper << endl;
   cout << endlist;

   cout << "Next free the middle pointer\n";
   heaper.free(p2);

   cout << startlist;
   cout << heaper << endl;
   cout << endlist;

   return 0;
}
```

Test Output

```
heap initialized

-------------BlockList start------------------
[2048,free]
-------------BlockList end------------------

Executing p1 = malloc(10):
malloc done

-------------BlockList start------------------
[10,allocated]  -> [2038,free]
-------------BlockList end------------------

Executing p2 = malloc(20):
malloc done

-------------BlockList start------------------
[10,allocated]  -> [20,allocated]  -> [2018,free]
-------------BlockList end------------------
```

```
Executing free(p1):

-------------BlockList start------------------
[10,free]  -> [20,allocated]  -> [2018,free]
-------------BlockList end------------------

malloc for a block too big for the initial open block
Executing p1 = malloc(15)
malloc done

-------------BlockList start------------------
[10,free]  -> [20,allocated]  -> [15,allocated]  ->
[2003,free]
-------------BlockList end------------------
```

Next free the most recently allocated pointer (p1)

```
-------------BlockList start------------------
[10,free]  -> [20,allocated]  -> [2018,free]
-------------BlockList end------------------
```

Next free p2

```
-------------BlockList start------------------
[2048,free]
-------------BlockList end------------------
```