CSCI 104
Memory Allocation

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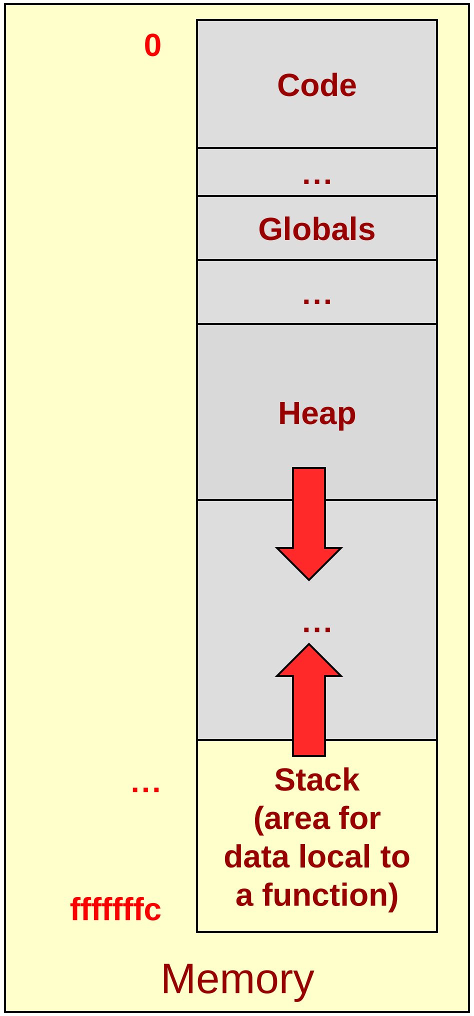
VARIABLES & SCOPE

A Program View of Memory

- Code usually sits at low addresses
- Global variables somewhere after code
- System stack (memory for each function instance that is alive)
  - Local variables
  - Return link (where to return)
  - etc.
- Heap: Area of memory that can be allocated and de-allocated during program execution (i.e. dynamically at run-time) based on the needs of the program
- Heap grows downward, stack grows upward…
  - In rare cases of large memory usage, they could collide and cause your program to fail or generate an exception/error



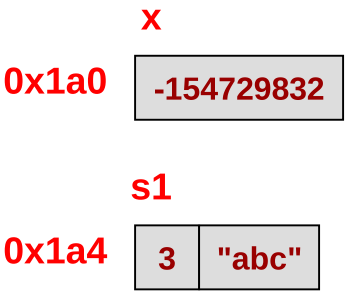
Variables and Static Allocation

- Every variable/object in a computer has a:
  - Name (by which *programmer* references it)
  - Address (by which *computer* references it)
  - Value
- Let's draw these as boxes
- Every variable/object has **scope** (its lifetime and visibility to other code)
- Automatic/Local Scope
  - {…} of a function, loop, or if
  - Lives on the stack
  - Dies/Deallocated when the '}' is reached
- Let's draw these as nested container boxes

Code

Computer

```
int x;

string s1("abc");
```



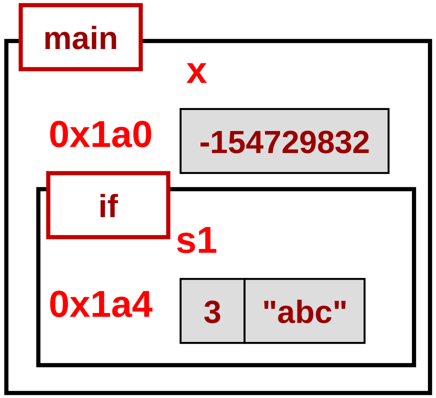
x

0x1a0 -154729832

s1

0x1a4 3 "abc"

```
int main()
{
  int x;
  if( x ){
    string s1("abc");
  }
}
```



main

x

0x1a0 -154729832

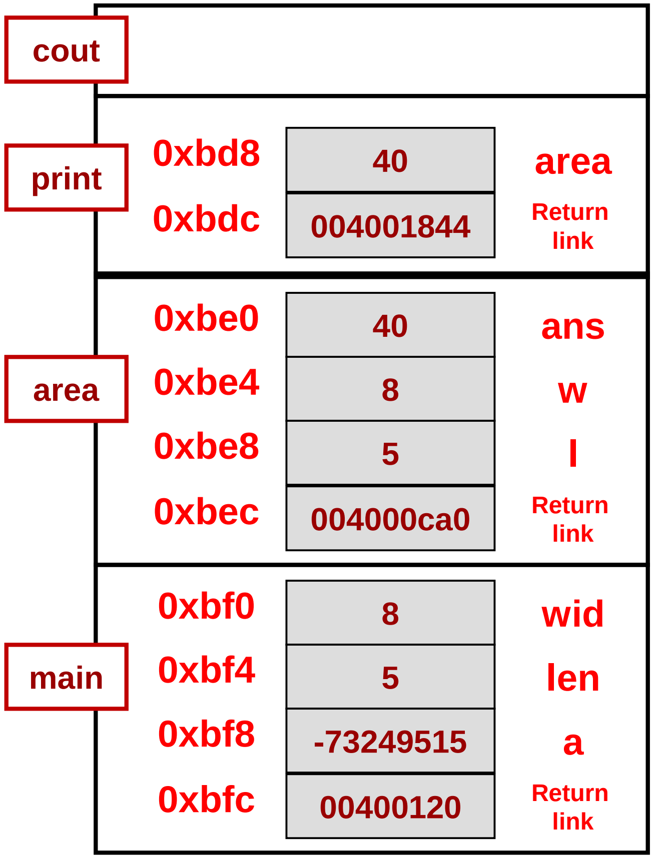
if

s1

0x1a4 3 "abc"

Automatic/Local Variables

- Variables declared inside {…} are allocated on the stack
- This includes functions



Stack Area of RAM

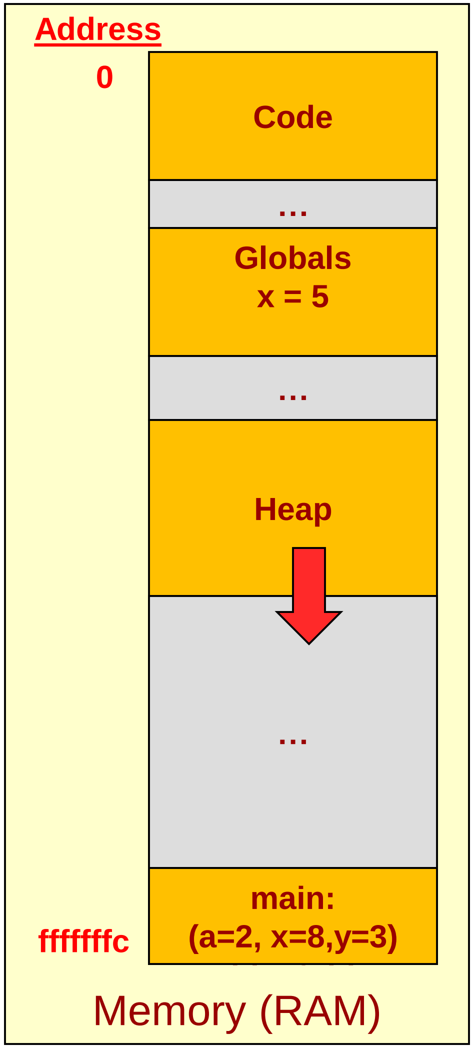
Frame	Address	Value	Name
cout			
print	0xbd8	40	area
	0xbdc	004001844	Return link
area	0xbe0	40	ans
	0xbe4	8	w
	0xbe8	5	l
	0xbec	004000ca0	Return link
main	0xbf0	8	wid
	0xbf4	5	len
	0xbf8	-73249515	a
	0xbfc	00400120	Return link

```
// Computes rectangle area,
//  prints it, & returns it
int area(int, int);
void print(int);

int main()
{
  int wid = 8, len = 5, a;
  a = area(wid,len);
}


int area(int w, int l)
{
  int ans = w * l;
  print(ans);
  return ans;
}


void print(int area)
{
  cout << “Area is “ << area;

  cout << endl;
}
```

Scope Example

- Globals live as long as the program is running
- Variables declared in a block { … } live as long as the block has not completed
  - { … } of a function
  - { … } of a loop, if statement, etc.
- When variables share the same name the closest declaration will be used by default

```
#include <iostream>
using namespace std;

int x = 5;

int main()
{
  int a, x = 8, y = 3;
  cout << “x = “ << x << endl;
  for(int i=0; i < 10; i++){
    int j = 1;
    j = 2*i + 1;
    a += j;
  }
  a = doit(y);
  cout << “a=“ << a ;
  cout << “y=“ << y << endl;
  cout << “glob. x” << ::x << endl;
}


int doit(int x)
{
   x--;
   return x;
}
```



Address

0

Code

…

Globals
x = 5

…

Heap

…

ffffffc

main:
(a=2, x=8,y=3)

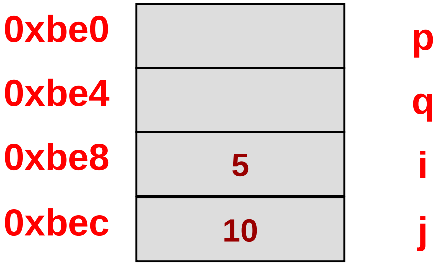
Memory (RAM)

POINTERS & REFERENCES

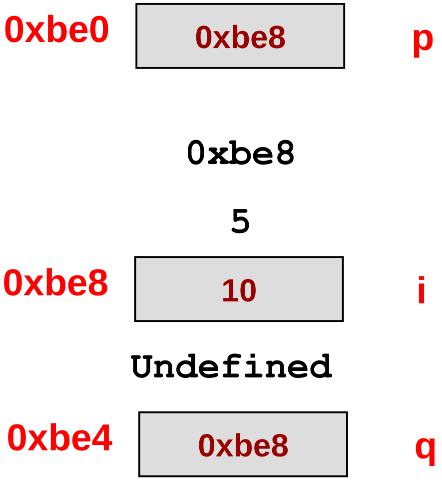
Pointers in C/C++

- Generally speaking a "reference" can be a pointer or a C++ Reference
- Pointer (type *)
  - Really just the memory address of a variable
  - Pointer to a data-type is specified as *type* * (e.g. int *)
  - Operators: & and *
    - &object => address-of object
    - *ptr => object located at address given by ptr
    - *(&object) => object [i.e. * and & are inverse operators of each other]
- Example

```
int* p, *q;
int i, j;

i = 5; j = 10;
p = &i;
cout << p << endl;
cout << *p << endl;
*p = j;
*q = *p;
q = p;
```



0xbe0		p
0xbe4		q
0xbe8	5	i
0xbec	10	j



0xbe0	0xbe8	p

0xbe8

5

0xbe8	10	i

Undefined

0xbe4	0xbe8	q

Pointer Notes

- An uninitialized pointer is a pointer just waiting to cause a SEGFAULT
- **`NULL`** (defined in <cstdlib>) or now **`nullptr`** (in C++11) are keywords for values you can assign to a pointer when it doesn't point to anything
  - NULL is effectively the value 0 so you can write:

```
int* p = NULL;
if( p )
 { /* will never get to this code */ }
```

  - To use nullptr compile with the C++11 version:

```
$ g++ -std=c++11 –g –o test test.cpp
```

- An uninitialized pointer is a pointer waiting to cause a SEGFAULT

Check Yourself

- Consider these declarations:
  - int k, x[3] = {5, 7, 9};
  - int *myptr = x;
  - int **ourptr = &myptr;
- Indicate the formal type that each expression evaluates to (i.e. int, int *, int **)

To figure out the type of data a pointer expression will yield…Take the type of pointer in the declaration and let each * in the expression 'cancel' one of the *'s in the declaration

Type	Expr	Yields
myptr = int*	*myptr	int
ourptr = int**	**ourptr	int
	*ourptr	int*

Expression	Type
x[0]	
x	
myptr	
*myptr	
(*ourptr) + 1	
myptr + 2	
ourptr	

References in C/C++

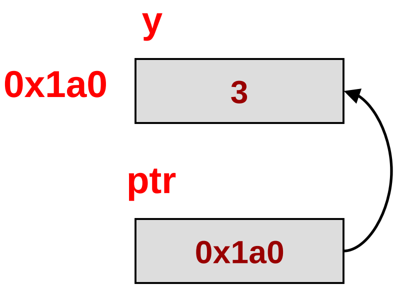
- Reference type (type &)
- "Syntactic sugar" to make it so you don't have to use pointers
  - Probably really using/passing pointers behind the scenes
- Declare a reference to an object as *type&* (e.g. int &)
- Must be initialized at declaration time (i.e. can't declare a reference variable if without indicating what object you want to reference)
  - Logically, C++ reference types DON'T consume memory…they are just an alias (another name) for the variable they reference
  - Physically, it may be implemented as a pointer to the referenced object but that is NOT your concern
- Cannot change what the reference variable refers to once initialized

Using C++ References

- Can use it within the same function
- A variable declared with an ‘int &’ doesn’t store an int, but is an alias for an actual variable
- MUST assign to the reference variable when you declare it.

```
int main()
{
  int y = 3, *ptr;
  ptr    = &y;  // address-of
                //  operator

 int &z;  // NO! must assign

 int &x = y;    // reference
                //  declaration
  // we’ve not copied
  // y into x
  // we’ve created an alias
  // Now x can never reference
  //   any other int…only y!

  x++;    // y just got incr.
  cout << y << endl;
  return 0;
}
```

With Pointers



y

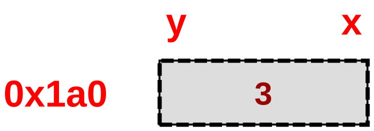
0x1a0

3

ptr

0x1a0

With References - Logically



y

x

0x1a0

3

Swap Two Variables

- Pass-by-value => Passes a copy
- Pass-by-reference =>
  - Pass-by-pointer/address => Passes address of actual variable
  - Pass-by-reference => Passes an alias to actual variable (likely its really passing a pointer behind the scenes but now you don't have to dereference everything)

```
int main()
{
  int x=5,y=7;
  swapit(x,y);
  cout <<“x,y=“<< x<<“,”<< y;
  cout << endl;
}

void swapit(int x, int y)
{
   int temp;
   temp = x;
   x = y;
   y = temp;
}
```

program output: x=5,y=7

```
int main()
{
  int x=5,y=7;
  swapit(&x,&y);
  cout <<“x,y=“<< x<<“,”<< y;
  cout << endl;
}

void swapit(int *x, int *y)
{
   int temp;
   temp = *x;
   *x = *y;
   *y = temp;
}
```

program output: x=7,y=5

```
int main()
{
  int x=5,y=7;
  swapit(x,y);
 cout <<“x,y=“<< x<<“,”<< y;
  cout << endl;
}

void swapit(int &x, int &y)
{
   int temp;
   temp = x;
   x = y;
   y = temp;
}
```

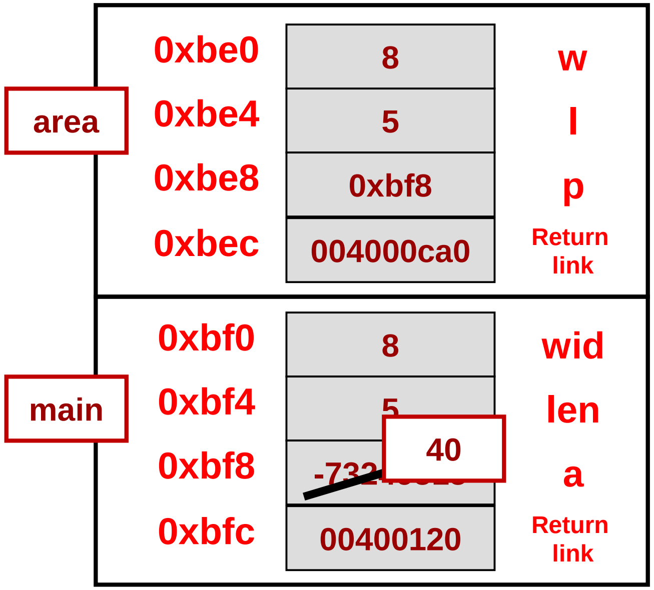
program output: x=7,y=5

Correct Usage of Pointers

- Can use a pointer to have a function modify the variable of another

```
// Computes rectangle area,
//  prints it, & returns it
void area(int, int, int*);


int main()
{
  int wid = 8, len = 5, a;
  area(wid,len,&a);
}


void area(int w, int l, int* p)
{
  *p = w * l;
}
```

Stack Area of RAM

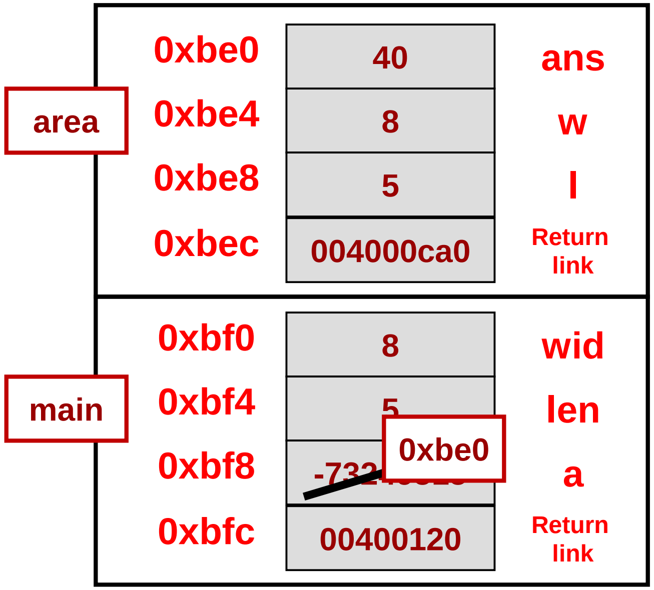


Misuse of Pointers

- Make sure you don't return a pointer to a dead variable
- You might get lucky and find that old value still there, but likely you won't

```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);


int main()
{
  int wid = 8, len = 5, *a;
  a = area(wid,len);
  cout << *a << endl;
}


int* area(int w, int l)
{
  int ans = w * l;

  return &ans;
}
```

Stack Area of RAM

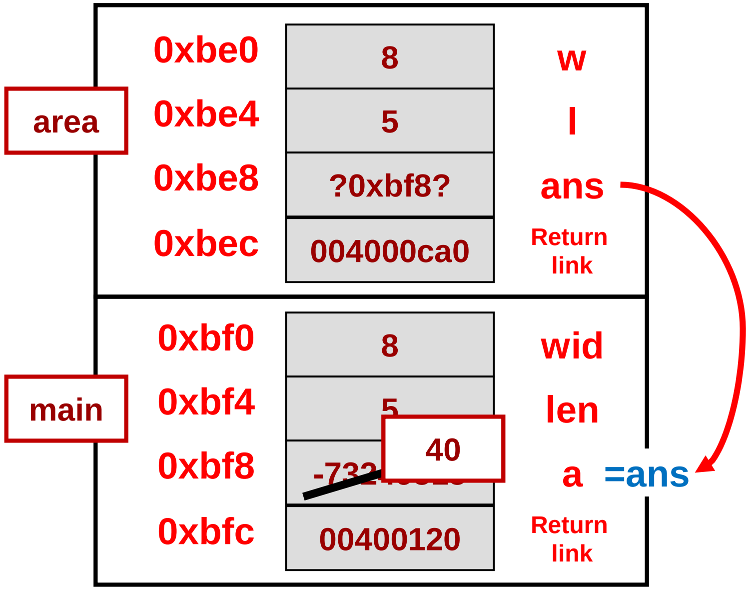


area	0xbe0	40	ans
	0xbe4	8	w
	0xbe8	5	l
	0xbec	004000ca0	Return link
main	0xbf0	8	wid
	0xbf4	5	len
	0xbf8	~~-732~~ 0xbe0	a
	0xbfc	00400120	Return link

Use of C++ References

- We can pass using C++ reference
- The reference 'ans' is just an alias for 'a' back in main
  - In memory, it might actually be a pointer, but you don't have to dereference (the kind of stuff you have to do with pointers)

Stack Area of RAM



```
// Computes rectangle area,
//  prints it, & returns it
void area(int, int, int&);


int main()
{
  int wid = 8, len = 5, a;
  area(wid,len,a);
}


void area(int w, int l, int& ans)
{
  ans = w * l;
}
```

Pass-by-Value vs. -Reference

- Arguments are said to be:
  - Passed-by-value: A copy is made from one function and given to the other
  - Passed-by-reference: A reference (really the address) to the variable is passed to the other function

Pass-by-Value Benefits	Pass-by-Reference Benefits
+ Protects the variable in the caller since a copy is made (any modification doesn't affect the original)	+ Allows another function to modify the value of variable in the caller + Saves time vs. copying

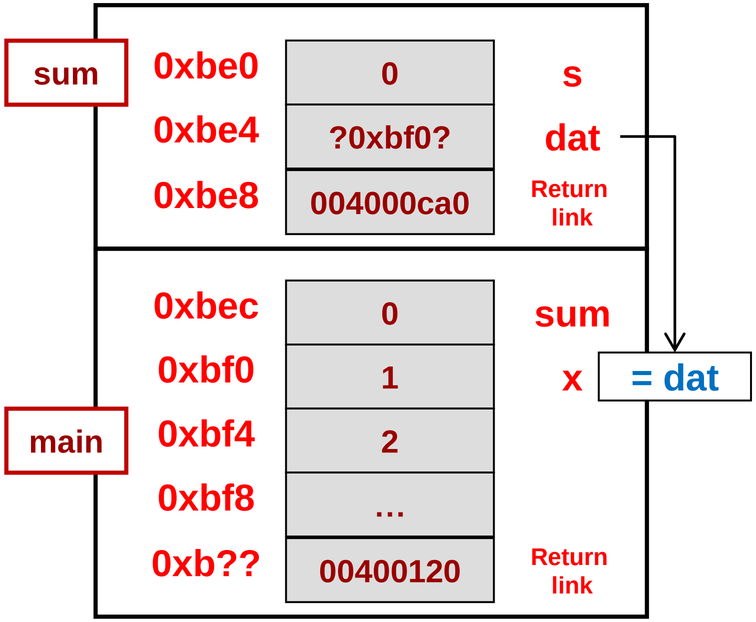
- Care needs to be taken when choosing between the options

Pass by Reference

- Notice no copy of x need be made since we pass it to sum() by reference
  - Notice that likely the computer passes the address to sum() but you should just think of **dat** as an alias for x

```
// Computes rectangle area,
//  prints it, & returns it
int sum(const vector<int>&);

int main()
{
  int result;
  vector<int> x = {1,2,3,4};
  result = sum(x);
}

int sum(const vector<int>& dat)
{
  int s = 0;
  for(int i=0; i < dat.size(); i++)
  {
     sum += dat[i];
  }
  return s;
}
```

Stack Area of RAM



Pointers vs. References

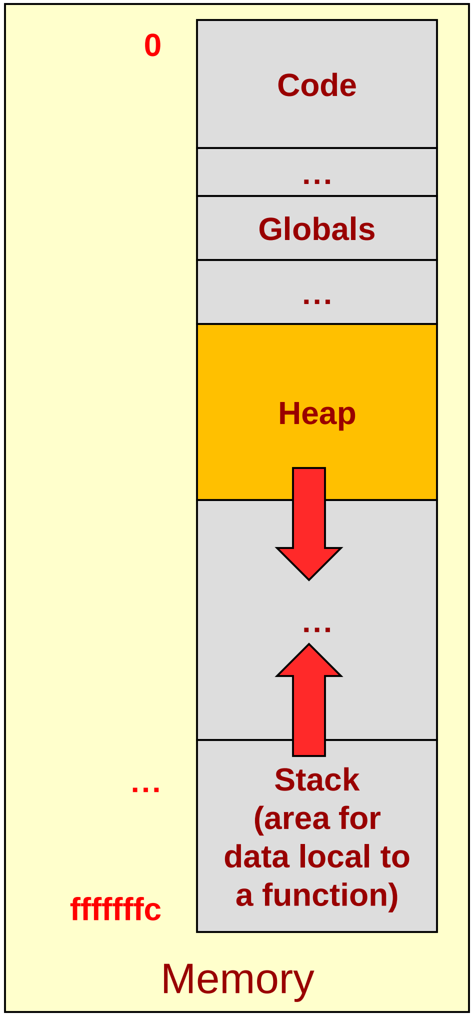
- How to tell references and pointers apart
  - Check if you see the '&' or '*' in a type declaration or expression

	Type	**Expression**
&	C++ Reference Var (int &val, vector<int> &vec)	Address-of (yields a pointer) &val => int *, &vec = vector<int>*
*	Pointer (int *valptr = &val, vector<int> *vecptr = &vec)	De-Reference (Value @ address) *valptr => val *vecptr => vec

DYNAMIC ALLOCATION

Dynamic Memory & the Heap

- Code usually sits at low addresses
- Global variables somewhere after code
- System stack (memory for each function instance that is alive)
  - Local variables
  - Return link (where to return)
  - etc.
- Heap: Area of memory that can be allocated and de-allocated during program execution (i.e. dynamically at run-time) based on the needs of the program
- Heap grows downward, stack grows upward…
  - In rare cases of large memory usage, they could collide and cause your program to fail or generate an exception/error



Motivation

Automatic/Local Variables

- Deallocated (die) when they go out of scope
- As a general rule of thumb, they must be statically sized (size is a constant known at compile time)
  - int data[100];

Dynamic Allocation

- Persist until explicitly deallocated by the program (via 'delete')
- Can be sized at run-time
  - int size;
    cin >> size;
    int *data = new int[size];

C Dynamic Memory Allocation

- void* malloc(*int num_bytes*) function in stdlib.h
  - Allocates the number of bytes requested and returns a pointer to the block of memory
  - Use sizeof(*type*) macro rather than hardcoding 4 since the size of an int may change in the future or on another system
- free*(void * ptr)* function
  - Given the pointer to the (starting location of the) block of memory, free returns it to the system for re-use by subsequent malloc calls

```
#include <iostream>
#include <cstdlib>

using namespace std;

int main(int argc, char *argv[])
{
  int num;

  cout << “How many students?” << endl;
  cin >> num;

  int *scores = (int*) malloc( num*sizeof(int) );
  // can now access scores[0] .. scores[num-1];

  free(scores);
  return 0;
}
```

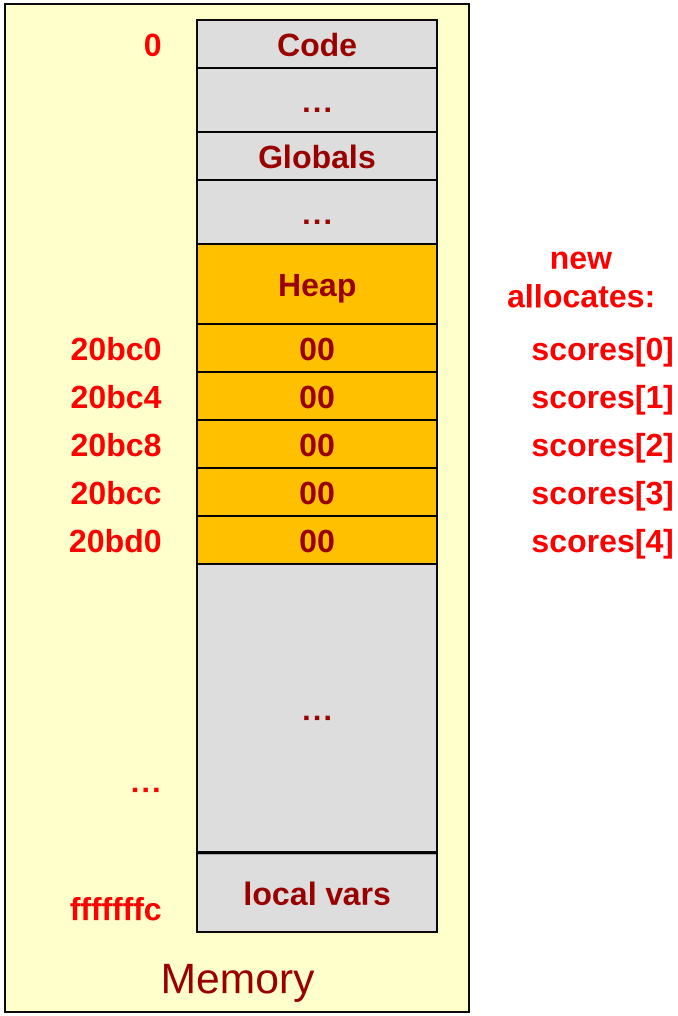
C++ `new` & `delete` operators

- new allocates memory from heap
  - followed with the type of the variable you want or an array type declaration
    - `double *dptr = new double;`
    - `int *myarray = new int[100];`
  - can obviously use a variable to indicate array size
  - returns a pointer of the appropriate type
    - if you ask for a new int, you get an int * in return
    - if you ask for an new array (new int[10]), you get an int * in return]
- delete returns memory to heap
  - followed by the pointer to the data you want to de-allocate
    - `delete dptr;`
  - use `delete []` for pointers to arrays
    - `delete [] myarray;`

Dynamic Memory Allocation

```
int main(int argc, char *argv[])
{
  int num;

  cout << “How many students?” << endl;
  cin >> num;

  int *scores = new int[num];
  // can now access scores[0] .. scores[num-1];
  return 0;
}
```

```
int main(int argc, char *argv[])
{
  int num;

  cout << “How many students?” << endl;
  cin >> num;

  int *scores = new int[num];
  // can now access scores[0] .. scores[num-1];
  delete [] scores
  return 0;
}
```



Fill in the Blanks

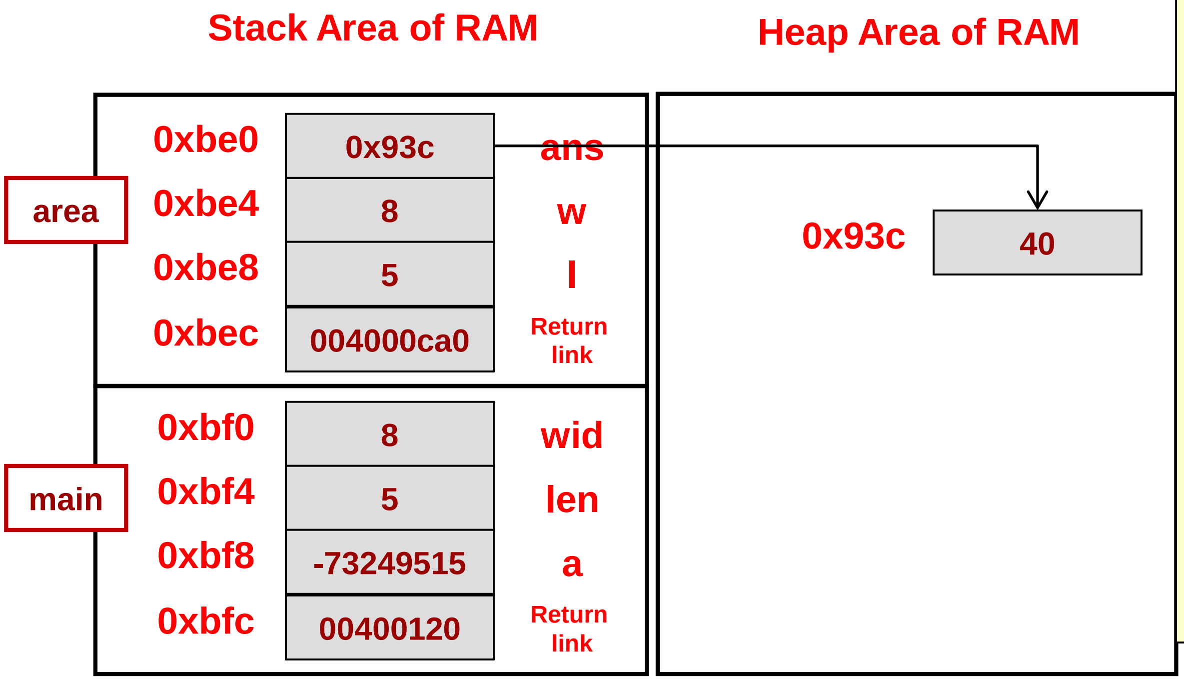
- _________ data = new int;
- _________ data = new char;
- _________ data = new char[100];
- _________ data = new char*[20];
- _________ data = new vector<string>;
- _________ data = new Student;

Fill in the Blanks

- _________ data = new int;
  - int*
- _________ data = new char;
  - char*
- _________ data = new char[100];
  - char*
- _________ data = new char*[20];
  - char**
- _________ data = new vector<string>;
  - vector<string>*
- _________ data = new Student;
  - Student*

Dynamic Allocation

- Dynamic Allocation
  - Lives on the heap
    - Doesn't have a name, only pointer/address to it
  - Lives until you 'delete' it
    - Doesn't die at end of function (though pointer to it may)
- Let's draw these as boxes in the heap area



Stack Area of RAM

Heap Area of RAM

area	0xbe0	0x93c	ans
	0xbe4	8	w
	0xbe8	5	l
	0xbec	004000ca0	Return link
main	0xbf0	8	wid
	0xbf4	5	len
	0xbf8	-73249515	a
	0xbfc	00400120	Return link

0x93c	40

```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);

int main()
{
  int wid = 8, len = 5, *a;
  a = area(wid,len);
  cout << *a << endl;
  delete a;
}

int* area(int w, int l)
{
  int* ans = new int;
  *ans = w * l;
  return ans;
}
```

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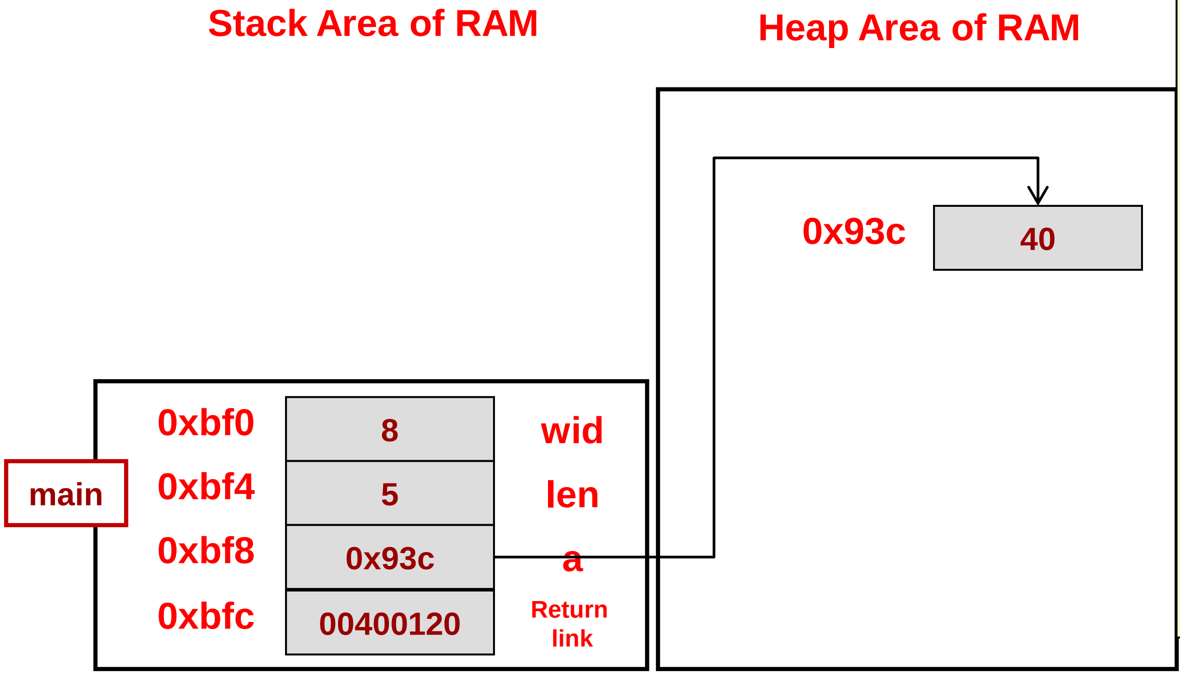

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void print(int);

int main()
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int* area(int w, int l)
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  int* ans = new int;
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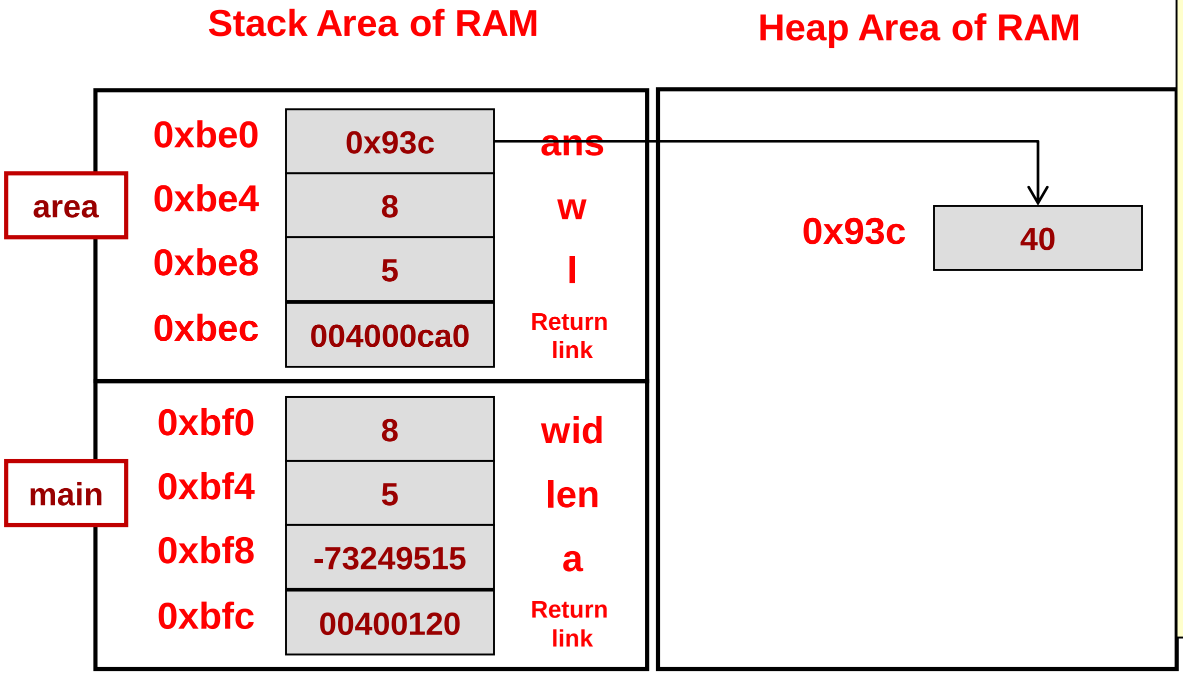
  return ans;
}
```



Stack Area of RAM

	Address	Value	Name
area	0xbe0	0x93c	ans
	0xbe4	8	w
	0xbe8	5	l
	0xbec	004000ca0	Return link
main	0xbf0	8	wid
	0xbf4	5	len
	0xbf8	-73249515	a
	0xbfc	00400120	Return link

Heap Area of RAM

Address	Value
0x93c	40

Dynamic Allocation

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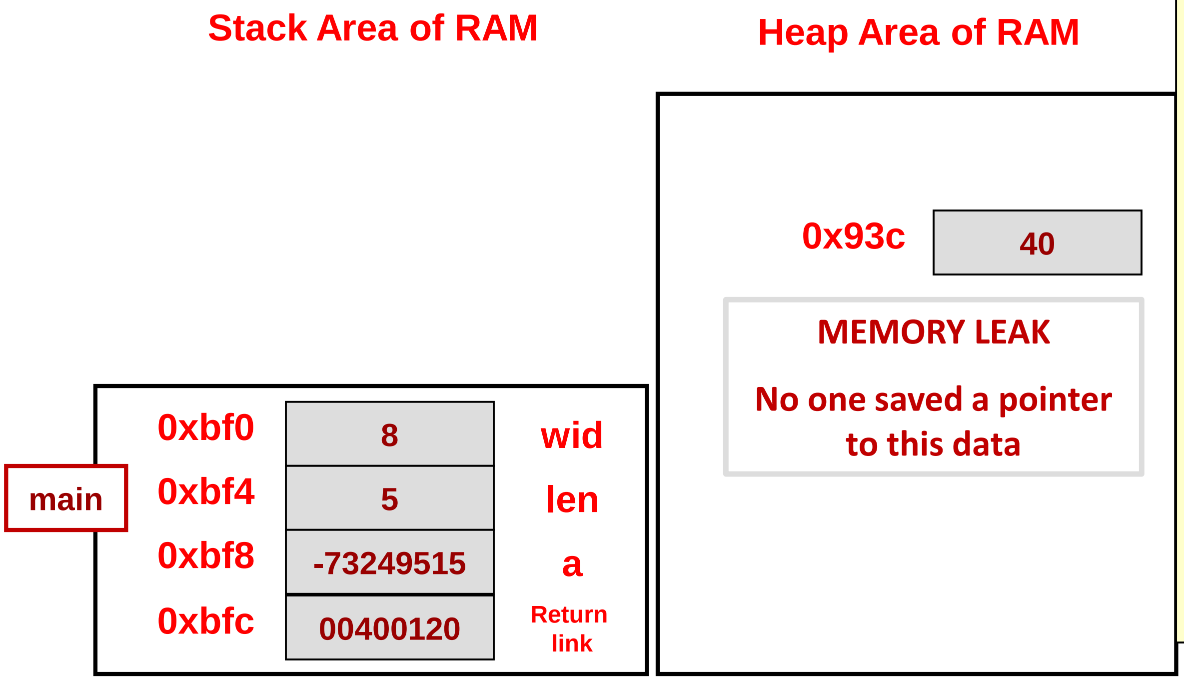

Stack Area of RAM

Heap Area of RAM

0x93c **40**

MEMORY LEAK

No one saved a pointer to this data

main

0xbf0	**8**	**wid**
0xbf4	**5**	**len**
0xbf8	**-73249515**	**a**
0xbfc	**00400120**	**Return link**

```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);
void print(int);

int main()
{
   int wid = 8, len = 5, a;
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int* area(int w, int l)
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Dynamic Allocation

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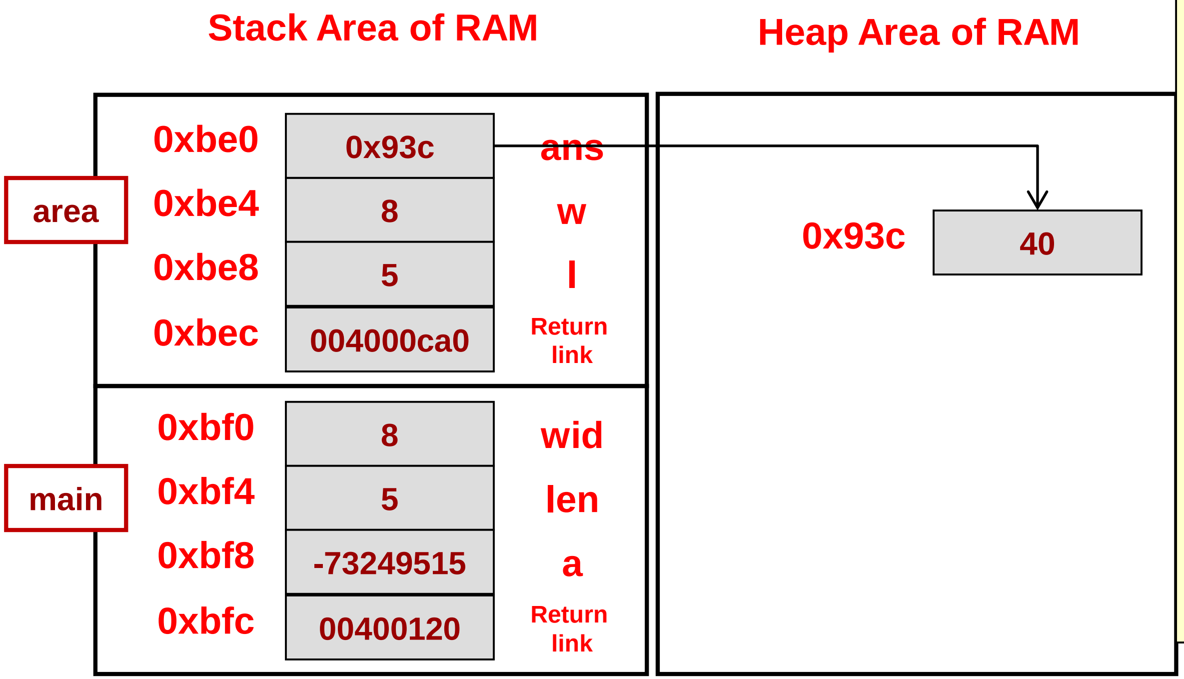
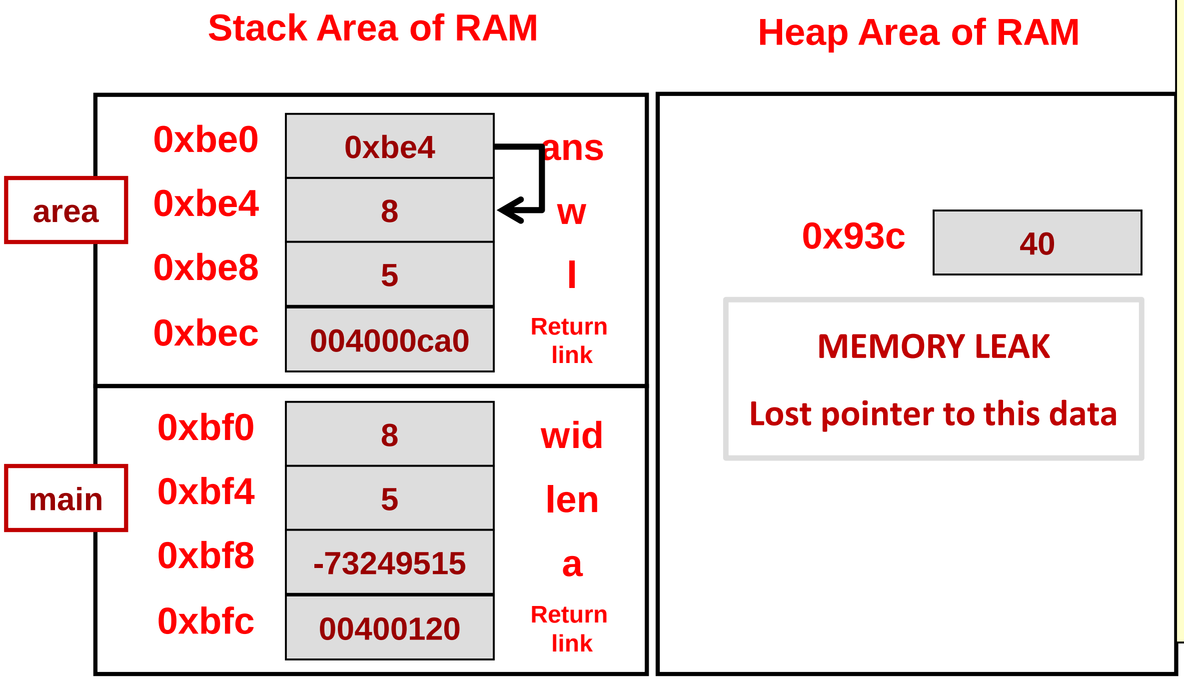


```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);
void print(int);

int main()
{
  int wid = 8, len = 5, a;
  area(wid,len);
}


int* area(int w, int l)
{
  int* ans = new int;
  ans = &w;
  return ans;
}
```

Dynamic Allocation

- Be sure you keep a pointer around somewhere otherwise you'll have a memory leak

```
// Computes rectangle area,
//  prints it, & returns it
int* area(int, int);
void print(int);

int main()
{
  int wid = 8, len = 5, a;
  area(wid,len);
}


int* area(int w, int l)
{
  int* ans = new int;
  ans = &w;
  return ans;
}
```



Stack Area of RAM

Heap Area of RAM

area

0xbe0 0xbe4 **ans**

0xbe4 8 **w**

0xbe8 5 **l**

0xbec 004000ca0 **Return link**

main

0xbf0 8 **wid**

0xbf4 5 **len**

0xbf8 -73249515 **a**

0xbfc 00400120 **Return link**

0x93c 40

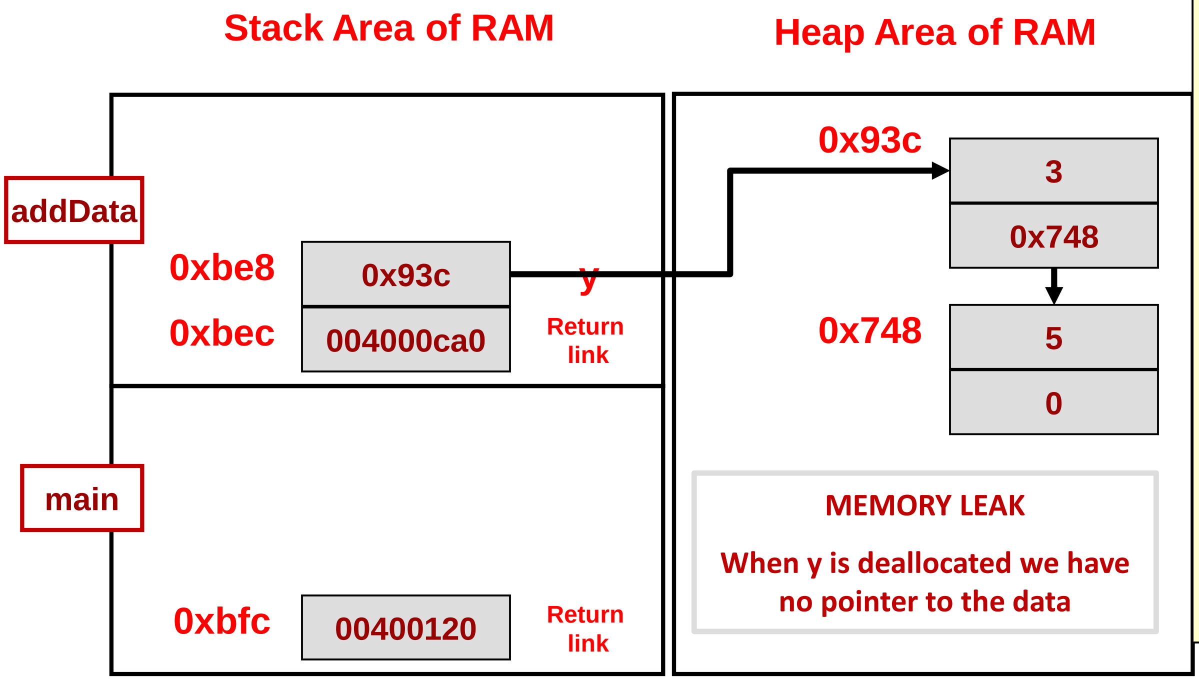
MEMORY LEAK

Lost pointer to this data

Dynamic Allocation

- The LinkedList object is allocated as a static/local variable
  - But each element is allocated on the heap
- When y goes out of scope only the data members are deallocated
  - You may have a memory leak

```
// Computes rectangle area,
//  prints it, & returns it
struct Item {
  int val;
  Item* next;
};
class LinkedList {
  public:
   void push_back(int v);
  private:
   Item* head;
};
int main()
{
  addData();
}

void addData()
{
  LinkedList y;
  y.push_back(3);
  y.push_back(5);
}
```



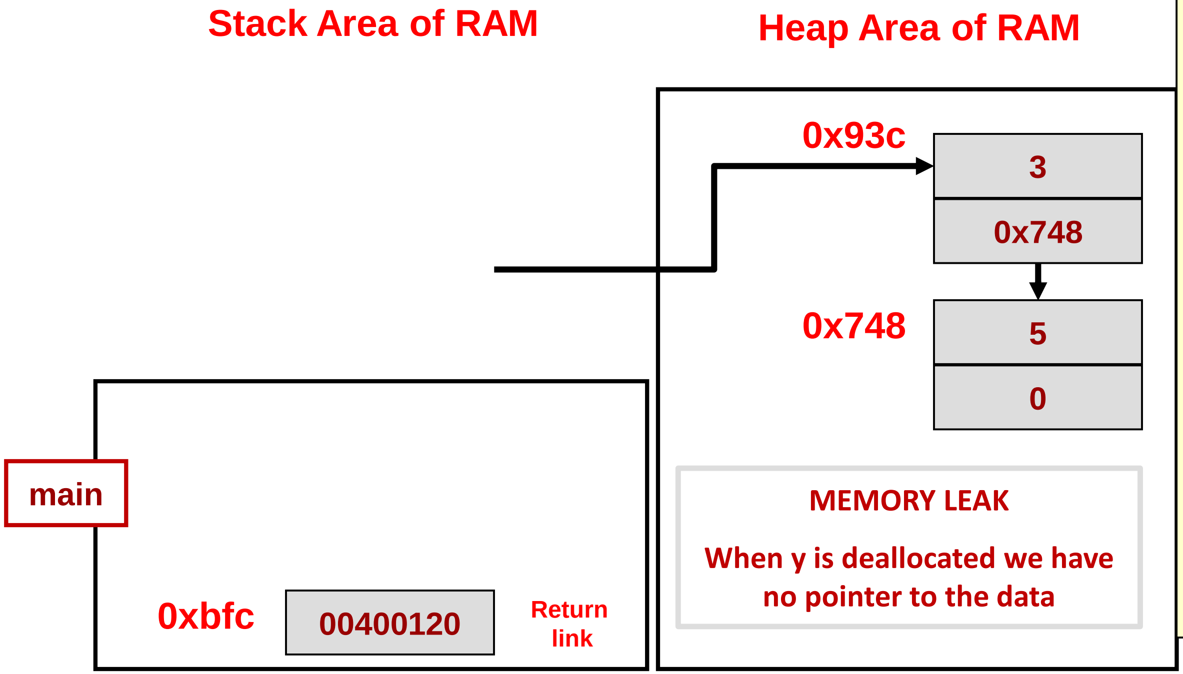
MEMORY LEAK

When y is deallocated we have no pointer to the data

Dynamic Allocation

- The LinkedList object is allocated as a static/local variable
  - But each element is allocated on the heap
- When x goes out of scope only the data members are deallocated
  - You may have a memory leak

An Appropriate Destructor Will Help Solve This



Stack Area of RAM

Heap Area of RAM

MEMORY LEAK

When y is deallocated we have no pointer to the data

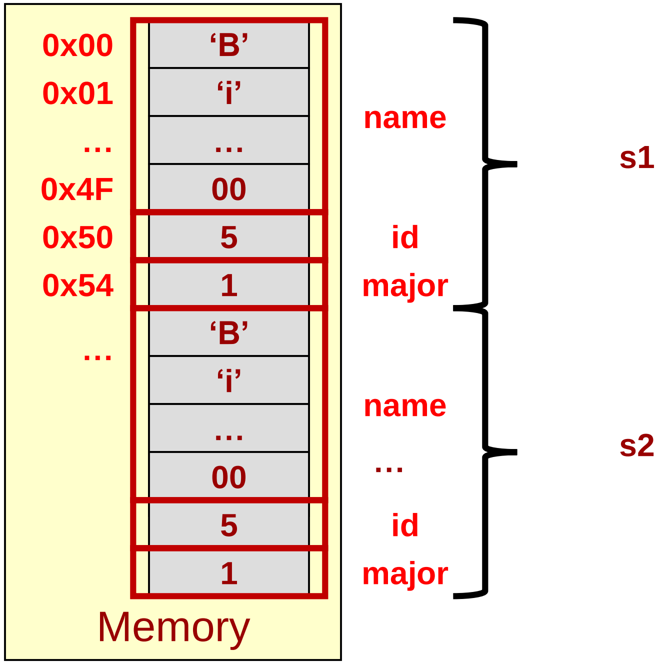
```
// Computes rectangle area,
//  prints it, & returns it
struct Item {
  int val;
  Item* next;
};
class LinkedList {
  public:
   void push_back(int v);
  private:
   Item* head;
};
int main()
{
  addData();
}

void addData()
{
  LinkedList y;
  y.push_back(3);
  y.push_back(5);
}
```

PRACTICE ACTIVITIES

Object Assignment

- Assigning one struct or class object to another will cause an element by element copy of the source data destination struct or class

```
#include<iostream>
using namespace std;

enum {CS, CECS };

struct student {
  char name[80];
  int id;
  int major;
};

int main(int argc, char *argv[])
{
  student s1;
  strncpy(s1.name,”Bill”,80);
  s1.id = 5; s1.major = CS;

  student s2 = s1;

  return 0;
}
```



Memory Allocation Tips

- Take care when returning a pointer or reference that the object being referenced will persist beyond the end of a function
- Take care when assigning a returned referenced object to another variable…you are making a copy
- Try the examples yourself
  - $ wget http://ee.usc.edu/~redekopp/cs104/memref.cpp

Understanding Memory Allocation

There are no syntax errors. Which of these can correctly build an Item and then have main() safely access its data

```
class Item
{ public:
   Item(int w, string y);
};
Item buildItem()
{ Item x(4, “hi”);
   return x;
}

int main()
{ Item i = buildItem();
   // access i’s data.

}
```

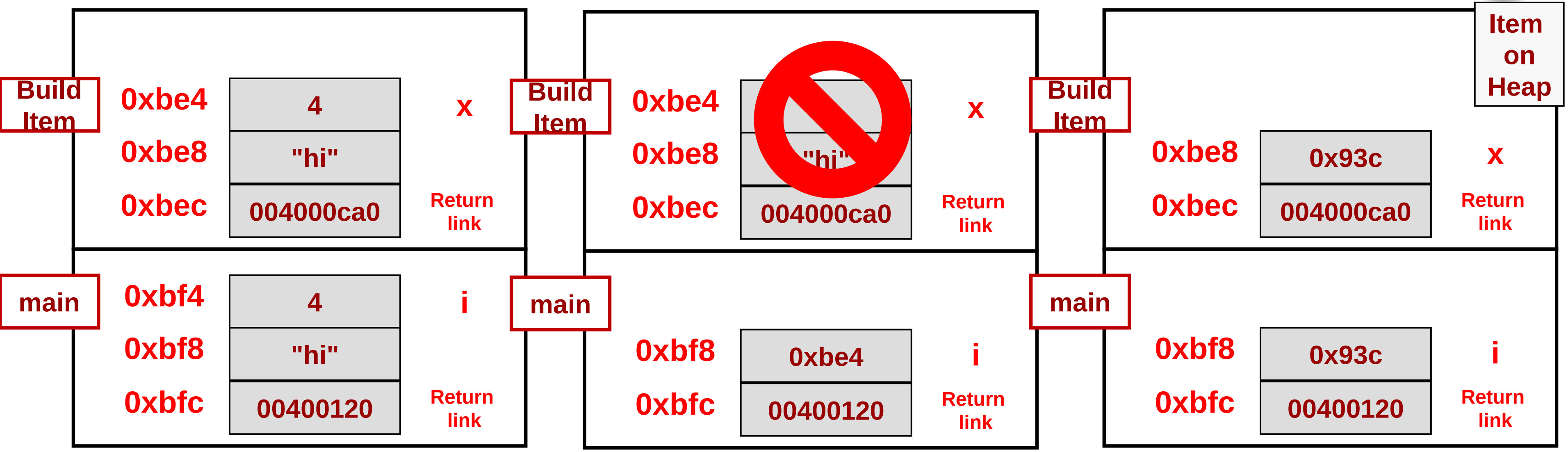
ex1 ✓

```
class Item
{ public:
   Item(int w, string y);
};
Item& buildItem()
{ Item x(4, “hi”);
   return x;
}

int main()
{ Item& i = buildItem();
   // access i’s data
}
```

ex2 ✗

```
class Item
{ public:
   Item(int w, string y);

};
Item* buildItem()
{ Item* x = new Item(4,“hi”);
   return x;
}

int main()
{ Item *i = buildItem();
   // access i’s data
}
```

ex3 ✓



Build Item	0xbe4	4	x
	0xbe8	"hi"	
	0xbec	004000ca0	Return link
main	0xbf4	4	i
	0xbf8	"hi"	
	0xbfc	00400120	Return link

Build Item	0xbe4		x
	0xbe8	"hi"	
	0xbec	004000ca0	Return link
main	0xbf8	0xbe4	i
	0xbfc	00400120	Return link

Item on Heap

Build Item	0xbe8	0x93c	x
	0xbec	004000ca0	Return link
main	0xbf8	0x93c	i
	0xbfc	00400120	Return link

Understanding Memory Allocation

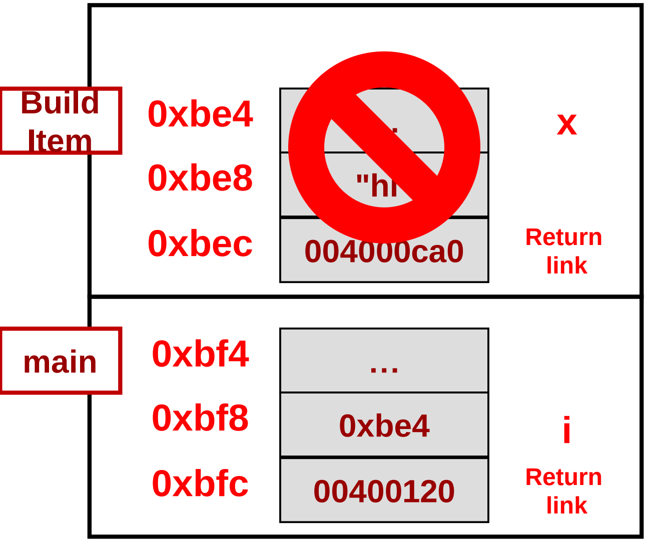
There are no syntax errors. Which of these can correctly build an Item and then have main() safely access its data

```
class Item
{ public:
  Item(int w, string y);

};
Item* buildItem()
{ Item x(4, "hi");
  return &x;
}

int main()
{ Item *i = buildItem();
  // access i's data

}
```

ex4 ✗

```
class Item
{ public:
  Item(int w, string y);

};
Item& buildItem()
{ Item* x = new Item(4,"hi");
  return *x;
}

int main()
{ Item& i = buildItem();
 // access i's data
}
```

ex5 ✓



Build Item

0xbe4 … x

0xbe8 "hi"

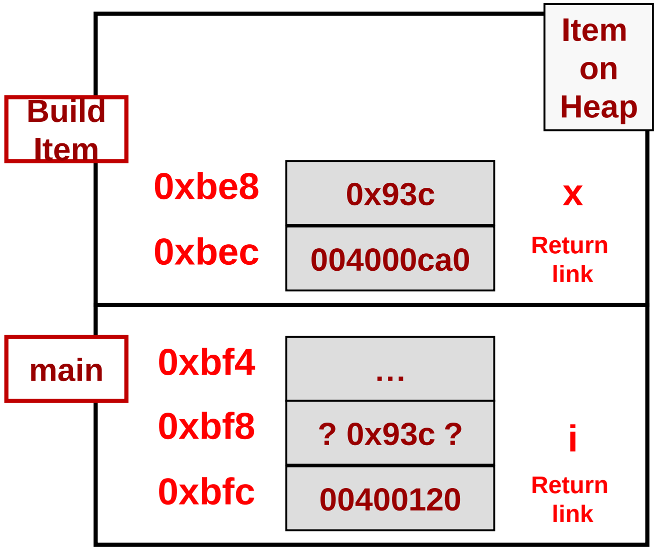
0xbec 004000ca0 Return link

main

0xbf4 …

0xbf8 0xbe4 i

0xbfc 00400120 Return link



Item on Heap

Build Item

0xbe8 0x93c x

0xbec 004000ca0 Return link

main

0xbf4 …

0xbf8 ? 0x93c ? i

0xbfc 00400120 Return link

Understanding Memory Allocation

```
class Item
{ public:
   Item(int w, string y);
};
Item& buildItem()
{ Item* x = new Item(4,"hi");
  return *x;
}

int main()
{ Item i = buildItem();
  // access i's data.
}
```

ex6

Item on Heap

Build Item	0xbe8	0x93c	x
	0xbec	004000ca0	Return link
main	0xbf4	4	i
	0xbf8	"hi"	
	0xbfc	00400120	Return link

```
class Item
{ public:
   Item(int w, string y);
};
Item& buildItem()
{ Item* x = new Item(4,"hi");
  return *x;
}

int main()
{ Item *i = &(buildItem());
  // access i's data.
}
```

ex7

Item on Heap

Build Item	0xbe8	0x93c	x
	0xbec	004000ca0	Return link
main	0xbf4	…	
	0xbf8	0x93c	i
	0xbfc	00400120	Return link

```
class Item
{ public:
   Item(int w, string y);

};
Item& buildItem()
{ Item* x = new Item(4,"hi");
  return *x;
}

int main()
{ Item &i = buildItem();
  // access i's data
}
```

ex8

Item on Heap

Build Item	0xbe8	0x93c	x
	0xbec	004000ca0	Return link
main	0xbf4	…	
	0xbf8	? 0x93c ?	i
	0xbfc	00400120	Return link

STREAMS REVIEW

Kinds of Streams

- I/O streams
  - Keyboard (cin) and monitor (cout)
- File streams – Contents of file are the stream of data
  - #include <fstream> and #include <iostream>
  - ifstream and ofstream objects
- String streams
  - #include <sstream> and #include iostream
  - sstream objects
- Streams support appropriate << or >> operators as well as .fail(), .getline(), .get(), .eof() member functions

C++ Stream Input

- cin, ifstreams, and stringstreams can be used to accept data from the user
  - int x;
  - cout << "Enter a number: ";
  - cin >> x;
- What if the user does not enter a valid number?
  - Check cin.fail( ) to see if the read worked
- What if the user enters multiple values?
  - >> reads up until the first piece of whitespace
  - cin.getline() can read a max number of chars until it hits a delimeter ***but only works for C-strings (character arrays)***

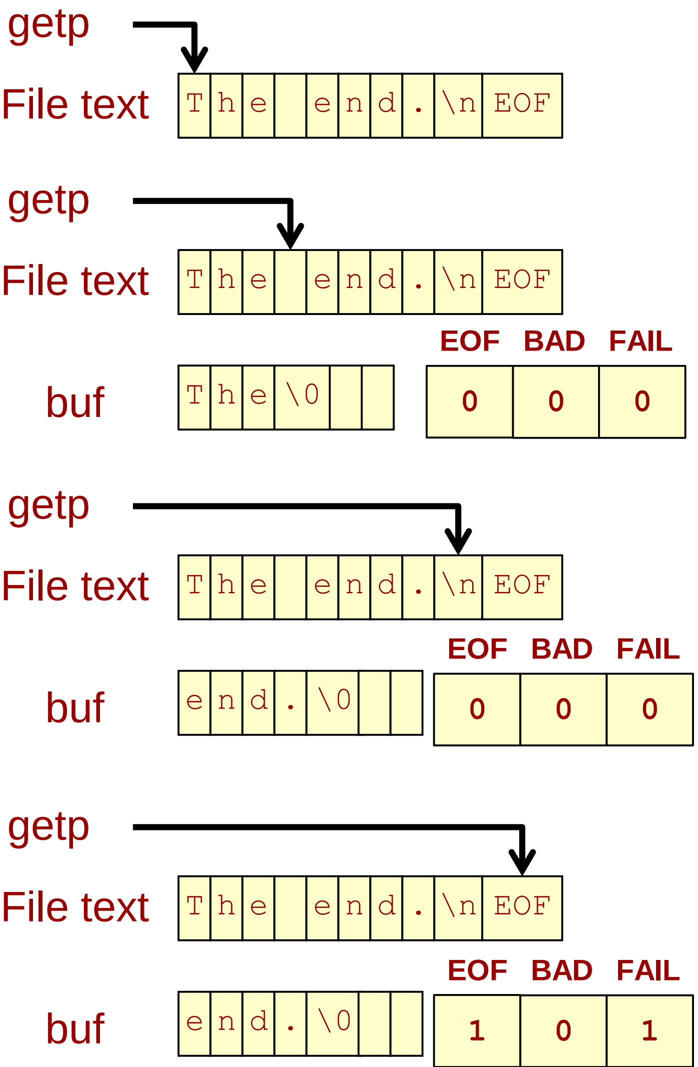
```
cin.getline(buf, 80) // reads everything through a '\n'
                     // stopping after 80 chars if no '\n'
cin.getline(buf, 80, ';') // reads everything through a ';'
                          // stopping after 80 chars if no ';'
```

  - The <string> header defines a getline(...) method that will read an entire line (including whitespace):

```
string x;
getline(cin,x,';'); // reads everything through a ';'
```

When Does It Fail

- For files & string streams the stream doesn't fail until you read PAST the EOF



```
char buf[40];
ifstream inf(argv[1]);
```

getp

File text

T	h	e		e	n	d	.	\n	EOF

```
inf >> buf;
```

getp

File text

T	h	e		e	n	d	.	\n	EOF

buf

T	h	e	\0		

EOF	BAD	FAIL
0	0	0

```
inf >> buf;
```

getp

File text

T	h	e		e	n	d	.	\n	EOF

buf

e	n	d	.	\0		

EOF	BAD	FAIL
0	0	0

```
inf >> buf;
```

getp

File text

T	h	e		e	n	d	.	\n	EOF

buf

e	n	d	.	\0		

EOF	BAD	FAIL
1	0	1

Which Option?

```
#include<iostream>
#include<fstream>
using namespace std;
int main()
{
 vector<int> nums;
 ifstream ifile("data.txt");
 int x;
 while( !ifile.fail() ){
   ifile >> x;
   nums.push_back(x);
 }
 ...
}
```

✗

data.txt

```
7 8 EOF
```

nums

_	_	_	_

```
#include<iostream>
#include<fstream>
using namespace std;
int main()
{
 vector<int> nums;
 ifstream ifile("data.txt");
 int x;
 while( 1 ){
   ifile >> x;
   if(ifile.fail()) break;
   nums.push_back(x);
 }
 ...
}
```

✓

Need to check for failure after you extract but before you store/use

```
int x;
while( ifile >> x ){
  nums.push_back(x);
}
...
```

✓

A stream returns itself after extraction

A stream can be used as a bool (returns true if it hasn't failed)

Choices

Where is my data?

Keyboard
(use ______)

File
(use ______)

String
(use _______)

Do I know how many items to read?

Yes, n items
Use ______

No, arbitrary
Use ______

Choices

What type of data?

Text

Integers/ Doubles

Is it delimited?

Yes

No

Yes

Choices

Where is my data?

Keyboard
(use iostream [cin])

File
(use ifstream)

String
(use stringstream)

Do I know how many items to read?

Yes, n items
Use for(i=0;i<n;i++)

No, arbitrary
Use while(cin >> temp) or while(getline(cin,temp))

Choices

What type of data?

Text
(getline or >>)
getline ALWAYS returns text

Ints/Doubles
(Use >> b/c it converts text to the given type)

Is it delimited?

Yes at newlines
Use getline()

No, stop on any whitespace…use >>

Yes at special chars
(';' or ',')
Use getline with 3rd input parameter
(delimeter parameter)

getline() and stringstreams

- Imagine a file has a certain format where you know related data is on a single line of text but aren't sure how many data items will be on that line
- Can we use >>?
  - No it doesn't differentiate between different whitespace (i.e. a ' ' and a '\n' look the same to >> and it will skip over them)
- We can use getline() to get the whole line, then a stringstream with >> to parse out the pieces

```
int num_lines = 0;
int total_words = 0;

ifstream myfile(argv[1]);

string myline;
while( getline(myfile, myline) ){

   stringstream ss(myline);

   string word;
   while( ss >> word )
     {  total_words++; }
   num_lines++;
}

double avg =
   (double) total_words / num_lines;

cout << "Avg. words per line: ";
cout << avg << endl;
```

```
The fox jumped over the log.

The bear ate some honey.

The CS student solved a hard problem.
```

Using Delimeters

- Imagine a file has a certain format where you know related data is on a single line of text but aren't sure how many data items will be on that line
- Can we use >>?
  - No it doesn't differentiate between different whitespace (i.e. a ' ' and a '\n' look the same to >> and it will skip over them)
- We can use getline() to get the whole line, then a stringstream with >> to parse out the pieces

Text file:

```
garbage stuff (words I care about) junk
```

```
vector<string> mywords;

ifstream myfile(argv[1]);

string myline;
getline(myfile, myline, '(');
// gets "garbage stuff "
// and throws away '('

getline(myfile, myline, ')' );
// gets "words I care about"
// and throws away ')'`

stringstream ss(myline);
string word;
while( ss >> word ) {
  mywords.push_back(word);
}
```

	0	1	2	3
mywords	"words"	"I"	"care"	"about"

Choosing an I/O Strategy

- Is my data delimited by particular characters?
  - Yes, stop on newlines: Use getline()
  - Yes, stop on other character: User getline() with optional 3rd character
  - No, Use >> to skip all whitespaces and convert to a different data type (int, double, etc.)
- If "yes" above, do I need to break data into smaller pieces (vs. just wanting one large string)
  - Yes, create a stringstream and extract using >>
  - No, just keep the string returned by getline()
- Is the number of items you need to read known as a constant or a variable read in earlier?
  - Yes, Use a loop and extract (>>) values placing them in array or vector
  - No, Loop while extraction doesn't fail placing them in vector

Remember: getline() always gives text/string.
To convert to other types it is easiest to use >>

RECURSION

Recursion

- Problem in which the solution can be expressed in terms of itself (usually a smaller instance/input of the same problem) ***and a base/terminating case***
- Input to the problem must be categorized as a:
  - Base case: Solution known beforehand or easily computable (no recursion needed)
  - Recursive case: Solution can be described using solutions to smaller problems of the same type
    - Keeping putting in terms of something smaller until we reach the base case
- Factorial: n! = n * (n-1) * (n-2) * … * 2 * 1
  - n! = n * (n-1)!
  - Base case: n = 1
  - Recursive case: n > 1 => n*(n-1)!

Recursive Definitions

- n = Non-Negative Integers and is defined as:
  - The number 0 [Base]
  - n + 1 where n is some non-negative integer [Recursive]
- String
  - Empty string, ε [Base]
  - String concatenated with a character (e.g. 'a'-'z') [Recursive]
- Palindrome (string that reads the same forward as backwards)
  - Example: dad, peep, level
  - Defined as:
    - Empty string [Base]
    - Single character [Base]
    - xPx where x is a character and P is a Palindrome [Recursive]
- Recursive definitions are often used in defining grammars for languages and parsers (i.e. your compiler)

C++ Grammar

- Languages have rules governing their syntax and meaning
- These rules are referred to as its grammar
- Programming languages also have grammars that code must meet to be compiled
  - Compilers use this grammar to check for syntax and other compile-time errors
  - Grammars often expressed as “productions/rules”
- ANSI C Grammar Reference:
  - http://www.lysator.liu.se/c/ANSI-C-grammar-y.html#declaration

Simple Paragraph Grammar

Substitution	Rule
subject	"I" | "You" | "We"
verb	"run" | "walk" | "exercise" | "eat" | "play" | "sleep"
sentence	subject verb '.'
sentence_list	sentence | sentence_list sentence
paragraph	[TAB = \t] sentence_list [Newline = \n]

Example:

```
   I run. You walk. We exercise.
   subject verb. subject verb.
subject verb.

   sentence sentence sentence
   sentence_list sentence sentence
   sentence_list sentence
   sentence_list
   paragraph
```

Example:

```
I eat You sleep
Subject verb subject verb
Error
```

C++ Grammar

Rule	Expansion
expr	constant | variable_id | function_call | assign_statement | ‘(‘ expr ‘)’ | expr binary_op expr | unary_op expr
assign_statement	variable_id ‘=‘ expr
expr_statement	‘;’ | expr ‘;’

Example:

`5 * (9 + max);`
expr * (*expr* + *expr*);
expr * (*expr*);
expr * *expr*;
expr;
expr_statement

Example:

`x + 9 = 5;`
expr + *expr* = *expr*;
expr = *expr*;

NO SUBSTITUTION
Compile Error!

C++ Grammar

Rule	Substitution
statement	expr_statement | compound_statement | if (expr) statement | while (expr) statement …
compound_statement	‘{‘ statement_list ‘}’
statement_list	statement | statement_list statement

Example:

```
while(x > 0) { doit(); x = x-2; }
while(expr) { expr; assign_statement; }
while(expr) { expr; expr; }
while(expr) { expr_statement expr_statement }
while(expr) { statement statement }
while(expr) { statement_list statement }
while(expr) { statement_list }
while(expr) compound_statement
while(expr) statement
statement
```

Example:

```
while(x > 0)
   x--;
   x = x + 5;
```

```
while(expr)
   statement
   statement
```

```
statement
statement
```

Recursive Functions

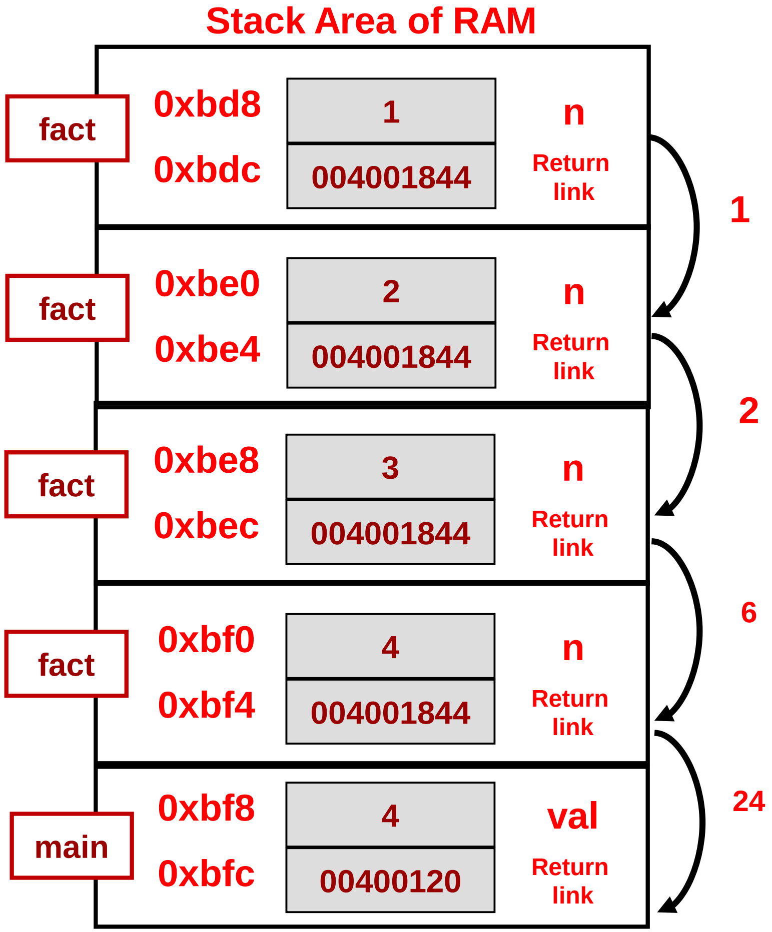
- Recall the system stack essentially provides separate areas of memory for each 'instance' of a function
- Thus each local variable and actual parameter of a function has its own value within that particular function instance's memory space

C Code:

```
int fact(int n)
{
  if(n == 1){
     // base case
     return 1;
  }
  else {
     // recursive case
     return n * fact(n-1);

  }
}
```

Recursion & the Stack

- Must return back through the each call



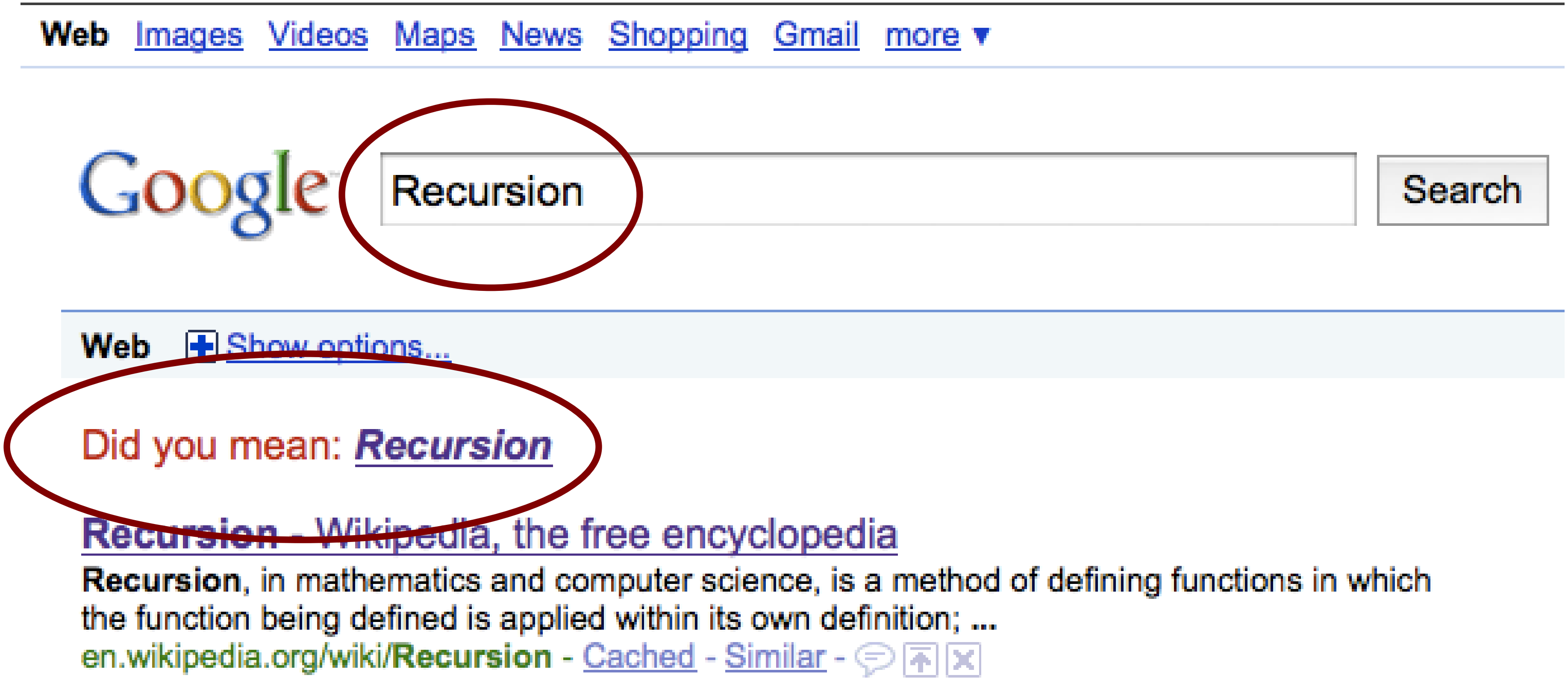
Stack Area of RAM

fact	0xbd8	1	n
	0xbdc	004001844	Return link
fact	0xbe0	2	n
	0xbe4	004001844	Return link
fact	0xbe8	3	n
	0xbec	004001844	Return link
fact	0xbf0	4	n
	0xbf4	004001844	Return link
main	0xbf8	4	val
	0xbfc	00400120	Return link

```
int fact(int n)
{
  if(n == 1){
     // base case
     return 1;
  }
  else {
     // recursive case
     return n * fact(n-1);
  }
}


int main()
{
  int val = 4;
  cout << fact(val) << endl;
}
```

Recursion

- **Google is in on the joke too...**



Did you mean: ***Recursion***

Recursion - Wikipedia, the free encyclopedia

Recursion, in mathematics and computer science, is a method of defining functions in which the function being defined is applied within its own definition; ...

en.wikipedia.org/wiki/**Recursion** - Cached - Similar -

Recursive Functions

- Many loop/iteration based approaches can be defined recursively as well

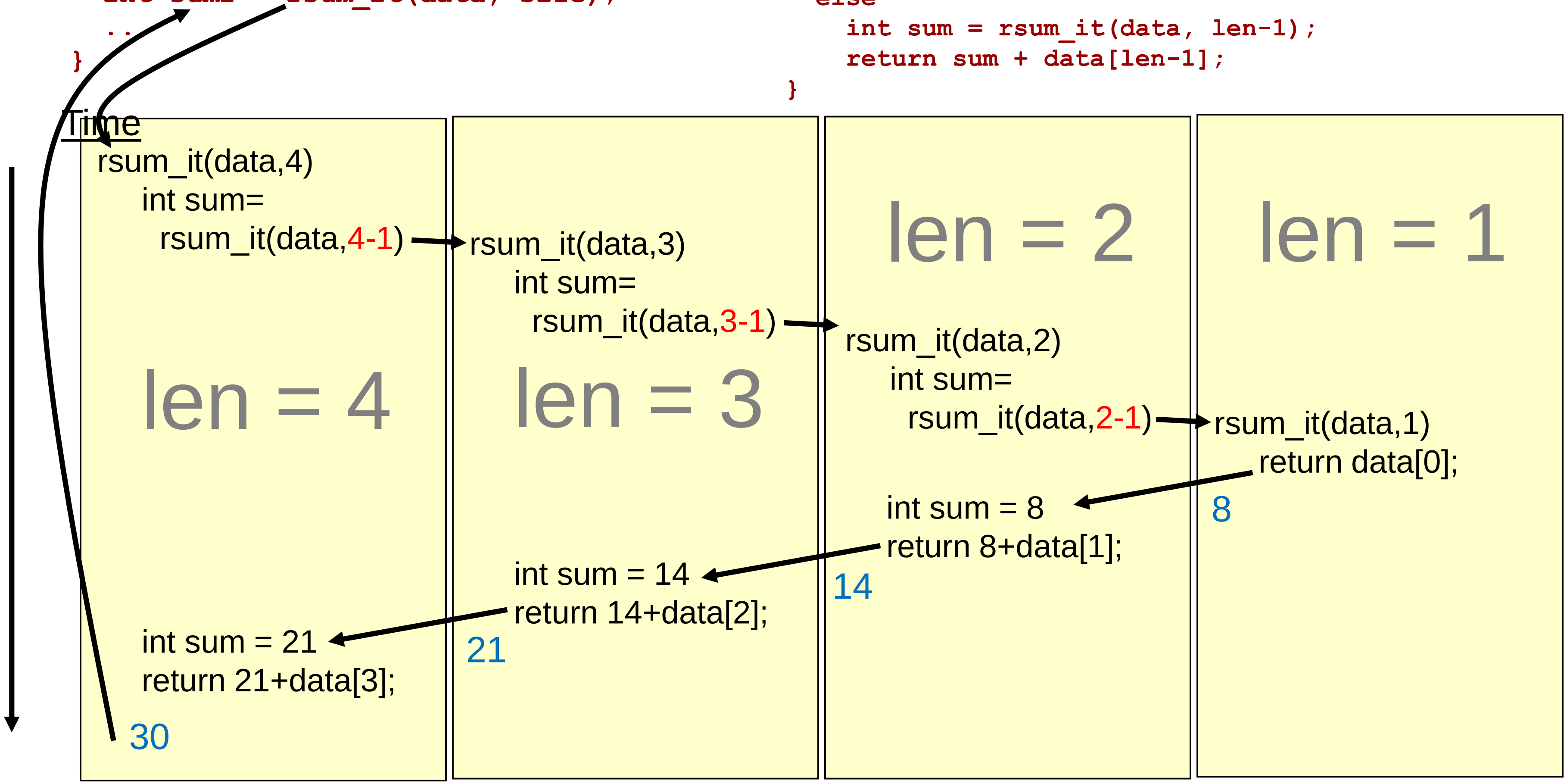
C Code:

```
int main()
{
  int data[4] = {8, 6, 7, 9};
  int size=4;
  int sum1 = isum_it(data, size);
  int sum2 = rsum_it(data, size);
}

int isum_it(int data[], int len)
{
  int sum = data[0];
  for(int i=1; i < len; i++){
    sum += data[i];
  }
}

int rsum_it(int data[], int len)
{
  if(len == 1)
    return data[0];
  else
    int sum = rsum_it(data, len-1);
    return sum + data[len-1];
}
```

Recursive Call Timeline

```
int main(){
  int data[4] = {8, 6, 7, 9};
  int size=4;
  int sum2 = rsum_it(data, size);
  ...
}
```

```
int rsum_it(int data[], int len)
{
  if(len == 1)
    return data[0];
  else
    int sum = rsum_it(data, len-1);
    return sum + data[len-1];
}
```



Each instance of rsum_it has its own len argument and sum variable

Every instance of a function has its own copy of local variables

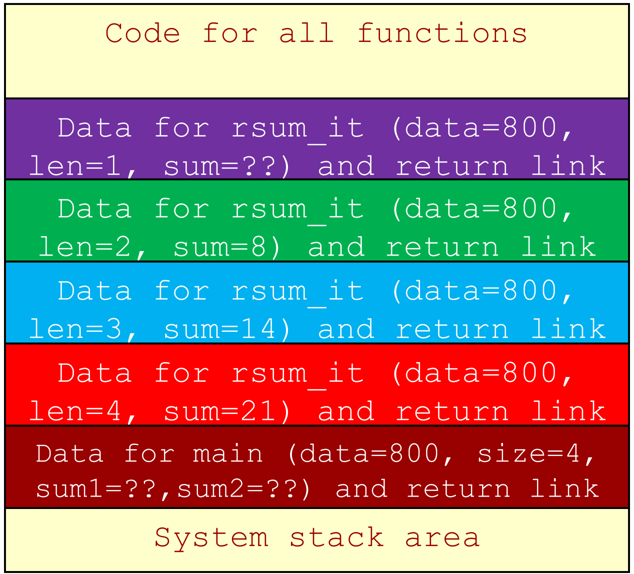
System Stack & Recursion

- The system stack makes recursion possible by providing separate memory storage for the local variables of each running instance of the function

```
int main()
{
  int data[4] = {8, 6, 7, 9};
  int size=4;
  int sum2 = rsum_it(data, size);
}

int rsum_it(int data[], int len)
{
  if(len == 1)
    return data[0];
  else
    int sum =
          rsum_it(data, len-1);
    return sum + data[len-1];
}
```

System Memory

(RAM)



Code for all functions

Data for rsum_it (data=800, len=1, sum=??) and return link

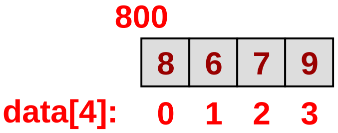
Data for rsum_it (data=800, len=2, sum=8) and return link

Data for rsum_it (data=800, len=3, sum=14) and return link

Data for rsum_it (data=800, len=4, sum=21) and return link

Data for main (data=800, size=4, sum1=??,sum2=??) and return link

System stack area



HELPER FUNCTIONS

Exercise

- Write a recursive routine to find the maximum element of an array containing POSITIVE integers.

```
int data[4] = {8, 9, 7, 6};
```

- Primary signature:

int max(int data, int len);*

- For recursion we usually need some parameter to tell use which item we are responsible for…thus the signature needs to change. We can make a helper function.
- The client uses the original:

int max(int data, int len);*

- But it just calls:

int max(int data, int len, int curr);*

Exercise – Helper Function

- Head recursion
- Tail recursion

```
int data[4] = {8, 9, 7, 6};
```

```
// The client only wants this
int max(int* data, int len);

// But to do the job we need this
int max(int* data, int len, int curr);
```

```
int max(int* data, int len)
{ return max(data, len, 0);
}

int max(int* data, int len, int curr)
{
  if(curr == len) return 0;
  else {
    int prevmax = max(data, len, curr+1);
    if(data[curr] > prevmax)
      return data[curr];
    else
      return prevmax;
}
```

```
// The client only wants this
int max(int* data, int len);

// But to do the job we need this
void max(int* data, int len, int curr, int& mx);
```

```
int max(int* data, int len)
{ int mymax = 0;
  max(data, len, 0, mymax);
  return mymax;
}

void max(int* data, int len, int curr, int& mx)
{
  if(curr == len) return;
  else {
    if(data[curr] > mx)
      mx = data[curr];
    max(data, len, curr+1, mx);
}
```

Exercise

- We can also formulate things w/o the helper function in this case…

```
int data[4] = {8, 6, 9, 7};
```

```
int max(int* data, int len)
{
  if(len == 1) return data[0];
  else {
    int prevmax = max(data, len-1);
    if(data[len-1] > prevmax)
      return data[len-1];
    else
      return prevmax;
  }
}
```

GENERATING ALL COMBINATIONS

Recursion's Power

- The power of recursion often comes when each function instance makes ***multiple*** recursive calls
- As you will see this often leads to exponential number of "combinations" being generated/explored in an easy fashion

Binary Combinations

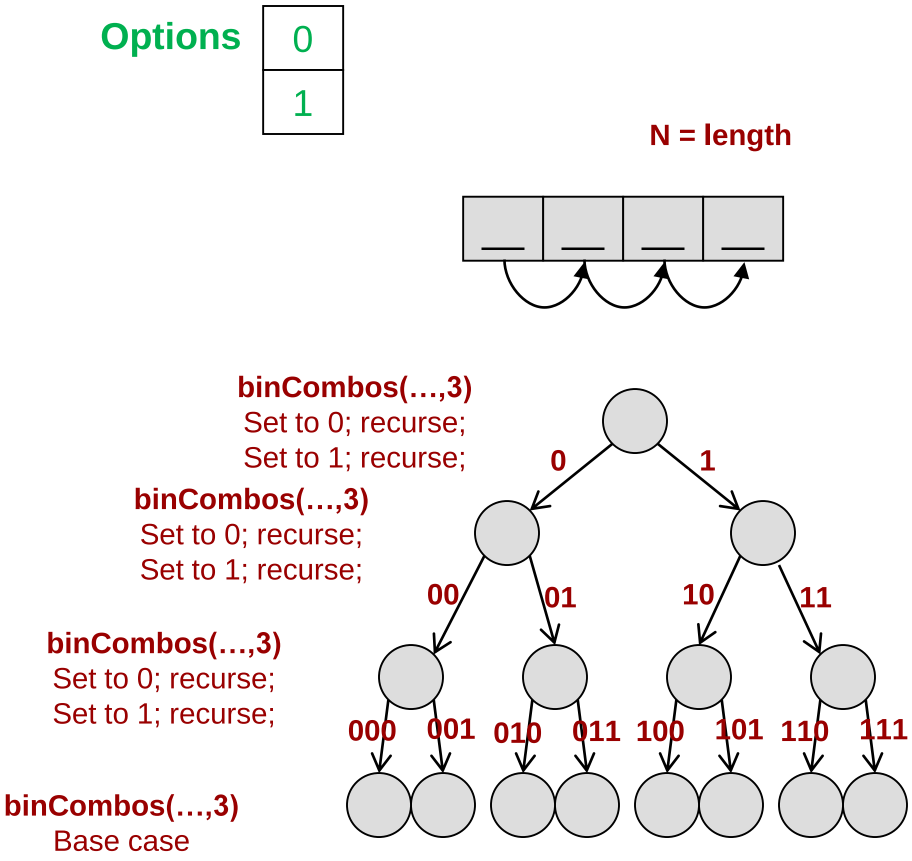
- If you are given the value, n, and a string with n characters could you generate all the combinations of n-bit binary?
- Do so recursively!

1-bit Bin.	2-bit Bin.	3-bit Bin.	4-bit Bin.
0	00	000	0000
1	01	001	0001
	10	010	0010
	11	011	0011
		100	0100
		101	0101
		110	0110
		111	0111
			1000
			1001
			1010
			1011
			1100
			1101
			1110
			1111

Exercise: bin_combo_str

Recursion and DFS

- Recursion forms a kind of Depth-First Search



binCombos(…,3)
Set to 0; recurse;
Set to 1; recurse;

binCombos(…,3)
Set to 0; recurse;
Set to 1; recurse;

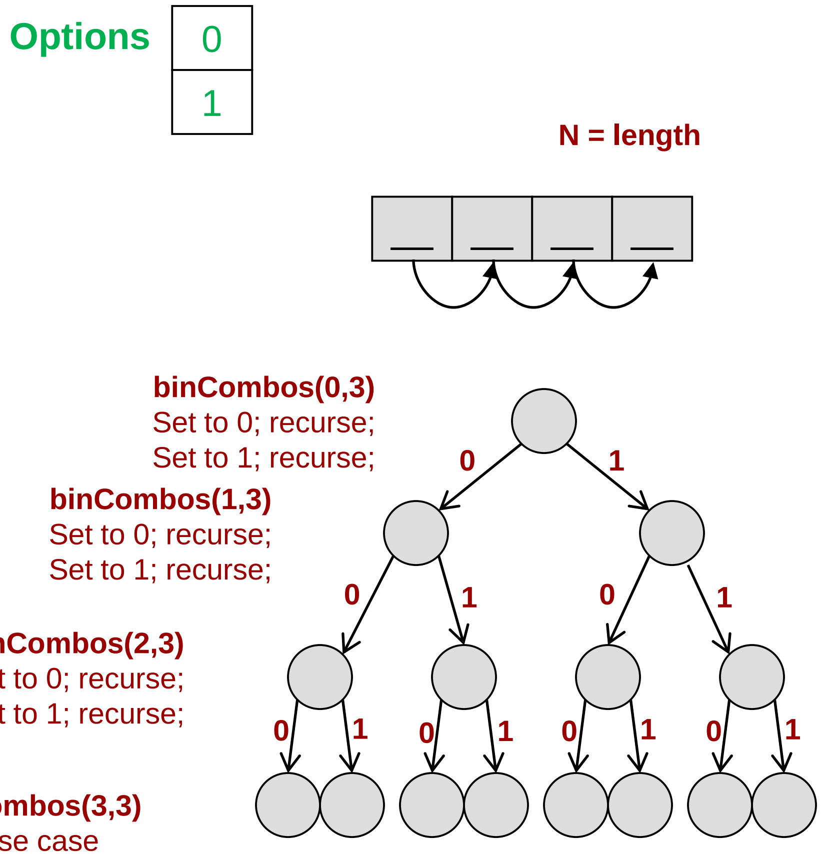
binCombos(…,3)
Set to 0; recurse;
Set to 1; recurse;

binCombos(…,3)
Base case

```
// user interface
void binCombos(int len)
{
  binCombos("", len);
}
// helper-function
void binCombos(string prefix,
               int len)
{
  if(prefix.length() == len )
    cout << prefix << endl;
  else {
    // recurse
    binCombos(prefix+"0", len);
    // recurse
    binCombos(prefix+"1", len);
  }
}
```

Recursion and DFS (w/ C-Strings)

- Recursion forms a kind of Depth-First Search



binCombos(0,3)
Set to 0; recurse;
Set to 1; recurse;

binCombos(1,3)
Set to 0; recurse;
Set to 1; recurse;

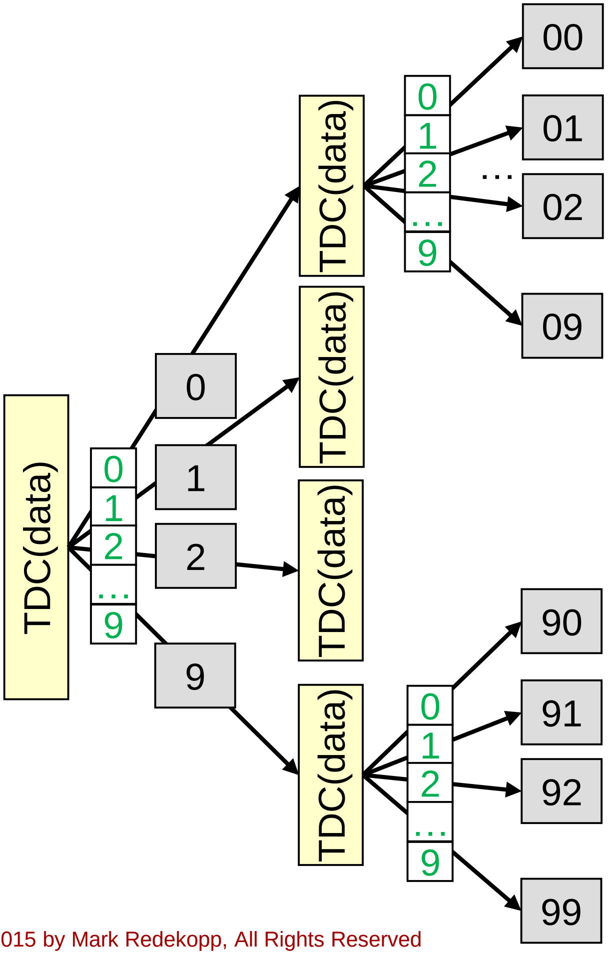
binCombos(2,3)
Set to 0; recurse;
Set to 1; recurse;

binCombos(3,3)
Base case

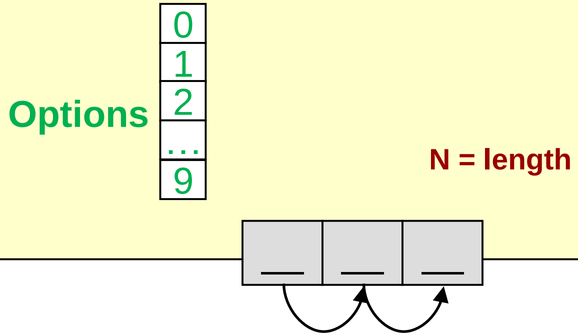
```
void binCombos(char* data,
               int curr,
               int len)
{
  if(curr == len )
    data[curr] = '\0';
  else {
    // set to 0
    data[curr] = '0';
    // recurse
    binCombos(data, curr+1, len);
    // set to 1
    data[curr] = '1';
    // recurse
    binCombos(data, curr+1, len);
  }
}
```

Generating All Combinations

- Recursion offers a simple way to generate all combinations of N items from a set of options, S
  - Example: Generate all 2-digit decimal numbers (N=2, S={0,1,…,9})



```
void TwoDigCombos(string data)
{
 if(data.size() == 2 )
  cout << data;
 else {
  for(int i=0; i < 10; i++){
   // recurse
   TwoDigCombos(data+(char)('0'+i));
  }
 }
}
```



Recursion and Combinations

- Recursion provides an elegant way of generating all **n**-length combinations of a set of values, S.
  - Ex. Generate all length-**n** combinations of the letters in the set **S**={'U','S','C'} (i.e. for n=2: UU, US, UC, SU, SS, SC, CU, CS, CC)
- General approach:
  - Need some kind of **array/vector/string** to store partial answer as it is being built
  - Each recursive call is only responsible for one of the **n** "places" (say location, **i**)
  - The function will iteratively (loop) try each option in **S** by setting location i to the current option, then recurse to handle all remaining locations (i+1 to n)
    - Remember you are responsible for only one location
  - Upon return, try another option value and recurse again
  - Base case can stop when all n locations are set (i.e. recurse off the end)
  - Recursive case returns after trying all options

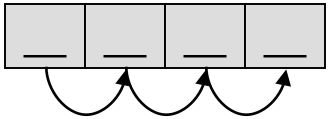
Another Exercise

- Generate all string combinations of length n from a given list (vector) of characters

Options

U
S
C

N = length



Use recursion to walk down the 'places'

At each 'place' iterate through & try all options

```
#include <iostream>
#include <string>
#include <vector>
using namespace std;

void all_combos(vector<char>& letters, int n) {

}

int main() {
   vector<char> letters;
   letters.push_back('U');
   letters.push_back('S');
   letters.push_back('C');

   all_combos(letters, 2);

   all_combos(letters, 4);

   return 0;
}
```

Exercises

- bin_combos_str
- Zero_sum
- Prime_products_print
- Prime_products
- basen_combos
- all_letter_combos

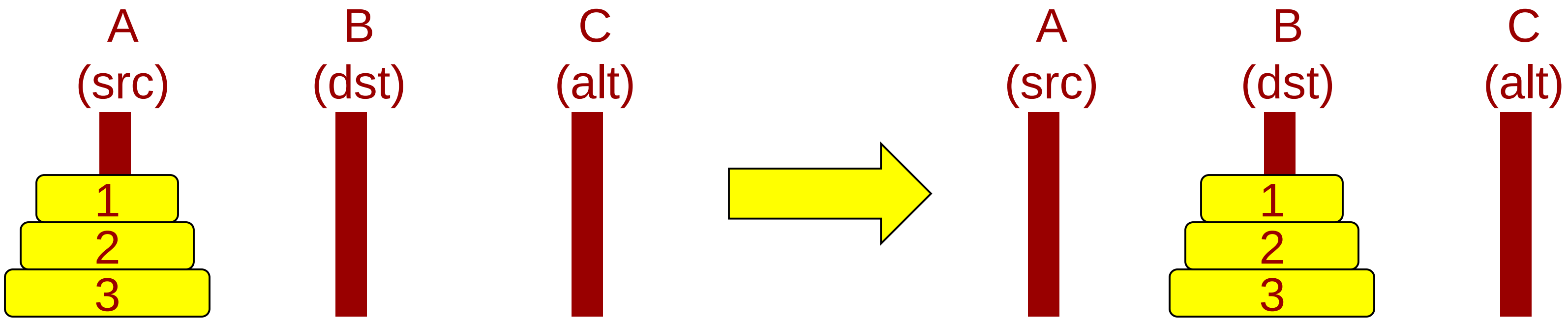
Follow slides are for your own review

END LECTURE

MORE EXAMPLES

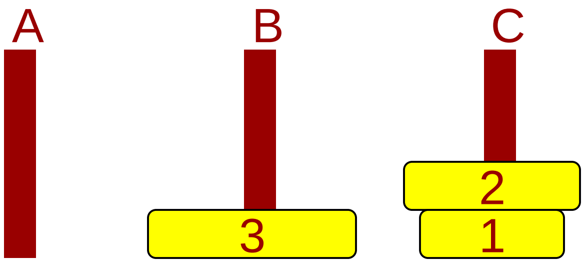
Towers of Hanoi Problem

- Problem Statements: Move n discs from source pole to destination pole (with help of a 3rd alternate pole)
  - Cannot place a larger disc on top of a smaller disc
  - Can only move one disc at a time



Start (n=3)

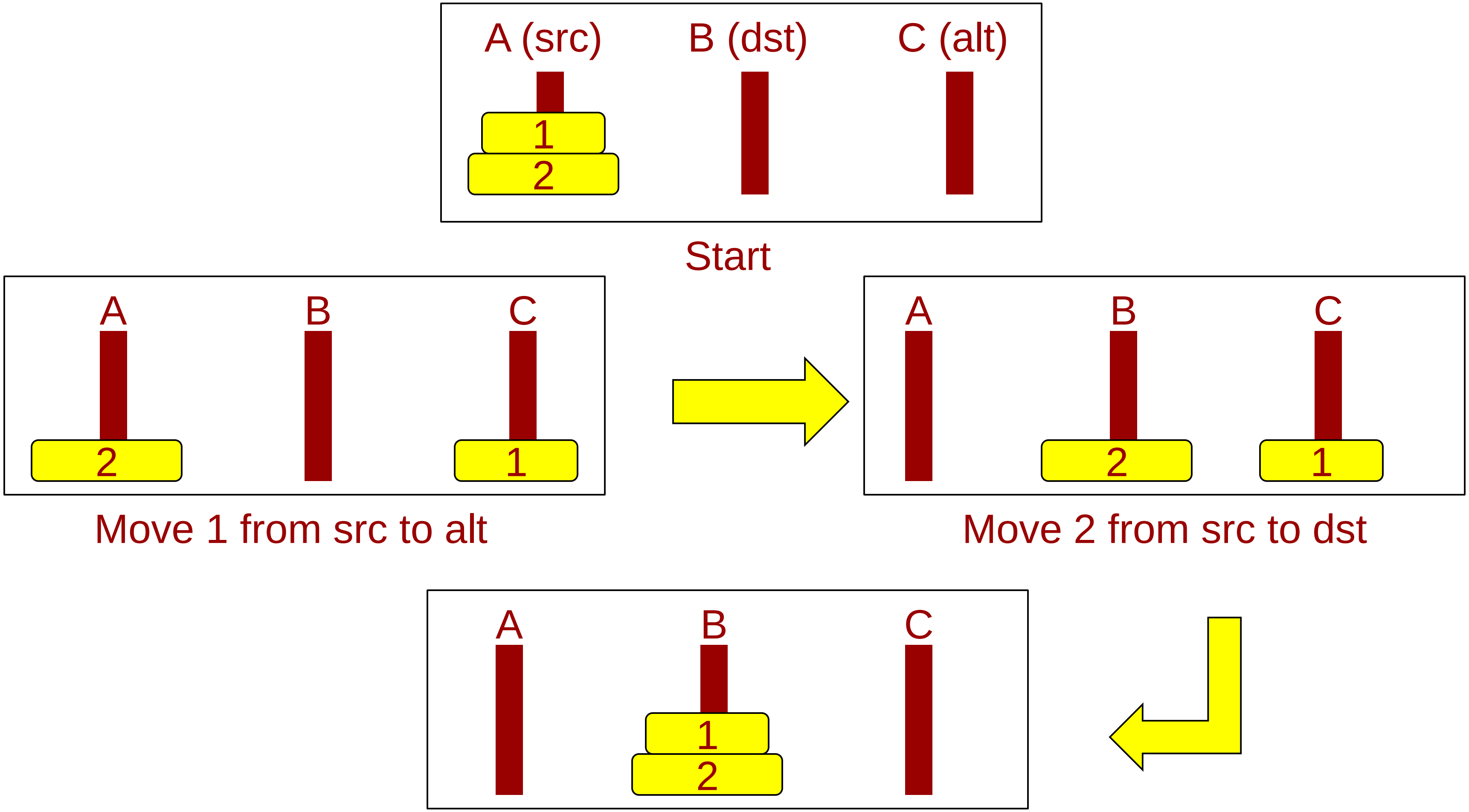
Goal (n=3)



Not allowed

Observation 1

- Observation 1: Disc 1 (smallest) can always be moved
- Solve the n=2 case:



Start

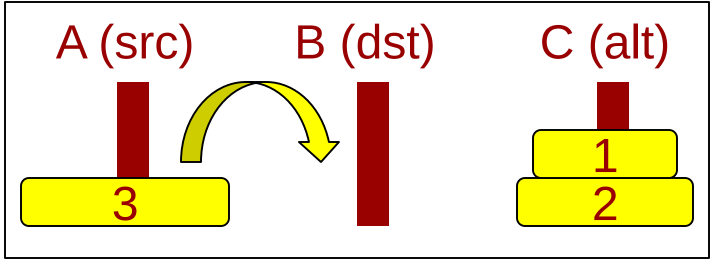
Move 1 from src to alt

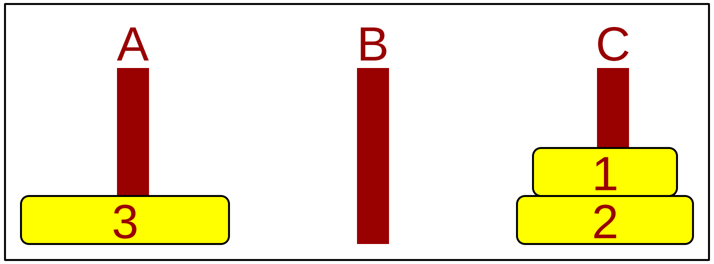
Move 2 from src to dst

Move 1 from alt to dst

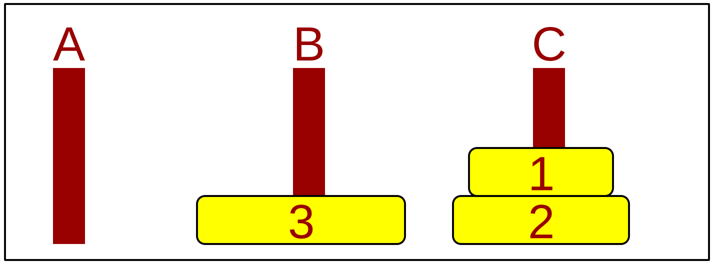
Observation 2

- Observation 2: If there is only one disc on the src pole and the dest pole can receive it the problem is trivial

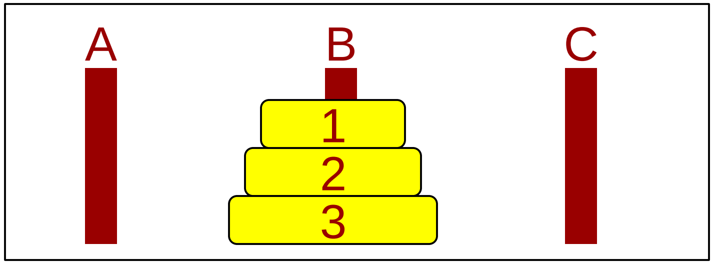




Move n-1 discs from src to alt



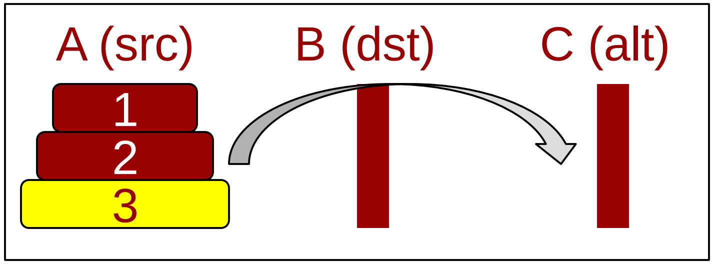
Move disc n from src to dst



Move n-1 discs from alt to dst

Recursive solution

- But to move n-1 discs from src to alt is really a smaller version of the same problem with
  - n => n-1
  - src=>src
  - alt =>dst
  - dst=>alt



- Towers(n,src,dst,alt)
  - Base Case: n==1 // Observation 1: Disc 1 always movable
    - Move disc 1 from src to dst
  - Recursive Case: // Observation 2: Move of n-1 discs to alt & back
    - Towers(n-1,src,alt,dst)
    - Move disc n from src to dst
    - Towers(n-1,alt,dst,src)

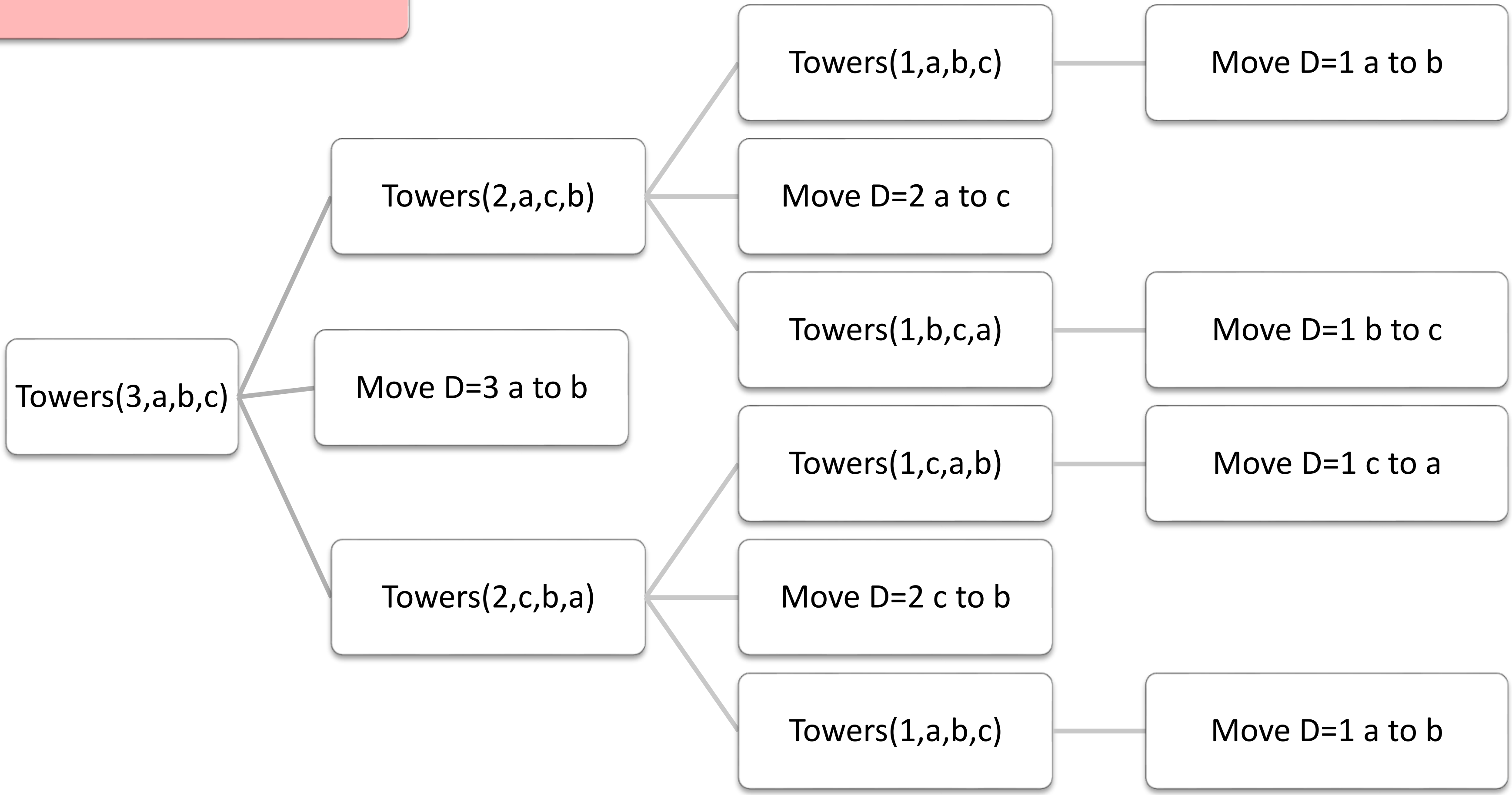
Exercise

- Implement the Towers of Hanoi code
  - $ wget http://ee.usc.edu/~redekopp/cs104/hanoi.cpp
  - Just print out "move disc=x from y to z" rather than trying to "move" data values
    - Move disc 1 from a to b
    - Move disc 2 from a to c
    - Move disc 1 from b to c
    - Move disc 3 from a to b
    - Move disc 1 from c to a
    - Move disc 2 from c to b
    - Move disc 1 from a to b

Recursive Box Diagram

Towers Function Prototype

Towers(disc,src,dst,alt)



Towers(3,a,b,c)

Towers(2,a,c,b)

Towers(1,a,b,c)

Move D=1 a to b

Move D=2 a to c

Towers(1,b,c,a)

Move D=1 b to c

Move D=3 a to b

Towers(2,c,b,a)

Towers(1,c,a,b)

Move D=1 c to a

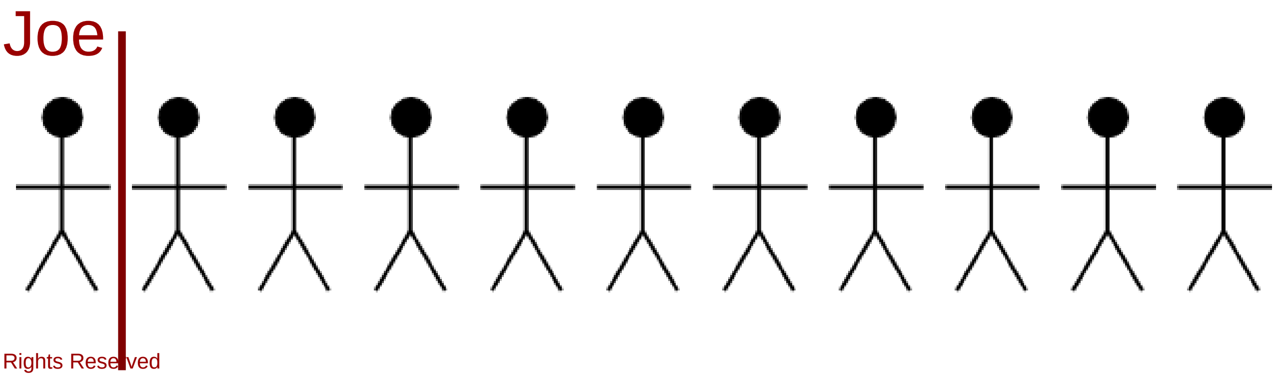
Move D=2 c to b

Towers(1,a,b,c)

Move D=1 a to b

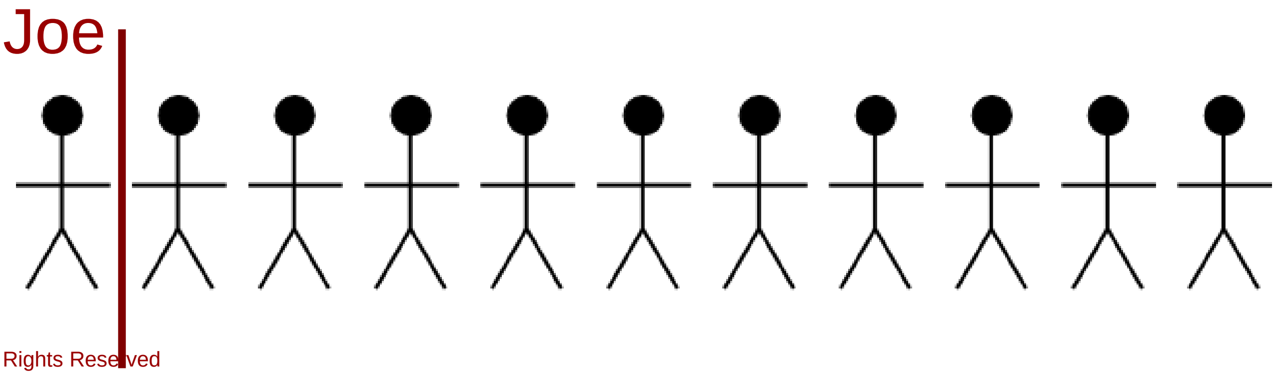
Combinatorics Examples

- Given n things, how can you choose k of them?
  - Written as C(n,k)
- How do we solve the problem?
  - Pick one person and single them out
    - Groups that contain Joe => ________________
    - Groups that don't contain Joe => ________________
  - Total number of solutions: _____________________
  - What are base cases?



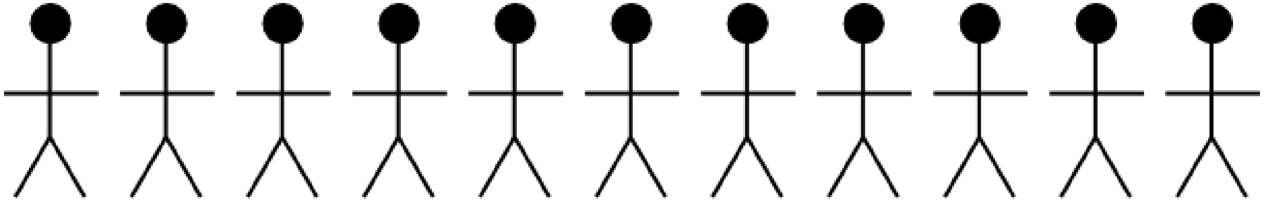
Combinatorics Examples

- Given n things, how can you choose k of them?
  - Written as C(n,k)
- How do we solve the problem?
  - Pick one person and single them out
    - Groups that contain Joe => C(n-1, k-1)
    - Groups that don't contain Joe => C(n-1, k)
  - Total number of solutions: C(n-1,k-1) + C(n-1,k)
  - What are base cases?



Combinatorics Examples

- You're going to Disneyland and you're trying to pick 4 people from your dorm to go with you
- Given n things, how can you choose k of them?
  - Written as C(n,k)
  - Analytical solution: C(n,k) = n! / [k! * (n-k)!]
- How do we solve the problem?



Recursive Solution

- Sometimes recursion can yield an incredibly simple solution to a very complex problem
- Need some base cases
  - C(n,0) = 1
  - C(n,n) = 1

```
int C(int n, int k)
{
if(k == 0 || k == n)
  return 1;
else
  return C(n-1,k-1) + C(n-1,k);
}
```

You are responsible for this on your own since its covered in CS103

C++ LIBRARY REVIEW

C++ Library

- String
- I/O Streams
- Vector

C Strings

- In C, strings are:
  - – Character arrays (char mystring[80])
  - – Terminated with a NULL character
  - – Passed by reference/pointer (char *) to functions
  - – Require care when making copies
    - Shallow (only copying the pointer) vs.
      Deep (copying the entire array of characters)
  - – Processed using C String library (<cstring>)

String Function/Library (cstring)

In C, we have to pass the C-String as an argument for the function to operate on it

- int strlen(char *dest)
- int strcmp(char *str1, char *str2);
  - Return 0 if equal, >0 if first non-equal char in str1 is alphanumerically larger, <0 otherwise
- char *strcpy(char *dest, char *src);
  - strncpy(char *dest, char *src, int n);
  - Maximum of n characters copied
- char *strcat(char *dest, char *src);
  - strncat(char *dest, char *src, int n);
  - Maximum of n characters concatenated plus a NULL
- char *strchr(char *str, char c);
  - Finds first occurrence of character ‘c’ in str returning a pointer to that character or NULL if the character is not found

```
#include <cstring>
using namespace std;
int main() {
  char temp_buf[5];
  char str[] = "Too much";
  strcpy(temp_buf, str);
  strncpy(temp_buf, str, 4);
  temp_buf[4] = '\0'
  return 0;
}
```

C++ Strings

- So you don't like remembering all these details?
  - You can do it! Don't give up.
- C++ provides a 'string' class that **abstracts** all those worrisome details and **encapsulates** all the code to actually handle:
  - Memory allocation and sizing
  - Deep copy
  - etc.

String Examples

- Must:
  - #include <string>
  - using namespace std;
- Initializations / Assignment
  - Use initialization constructor
  - Use '=' operator
  - Can reassign and all memory allocation will be handled
- Redefines operators:
  - + (concatenate / append)
  - += (append)
  - ==, !=, >, <, <=, >= (comparison)
  - [] (access individual character)

```
#include <iostream>
#include <string>
using namespace std;

int main(int argc, char *argv[]) {
  int len;
  string s1("CS is ");
  string s2 = "fun";
  s2 = "really fun";
  cout << s1 << " is " << s2 << endl;
  s2 = s2 + “!!!”;
  cout << s2 << endl;
  string s3 = s1;
  if (s1 == s3){
    cout << s1 << " same as " << s3;
    cout << endl;

  }
  cout << “First letter is “ << s1[0];
  cout << endl;

}
```

Output:

```
CS is really fun
really fun!!!
CS is  same as CS is
First letter is C
```

http://www.cplusplus.com/reference/string/string/

More String Examples

- Size/Length of string
- Get C String (char *) equiv.
- Find a substring
  - Searches for occurrence of a substring
  - Returns either the index where the substring starts or string::npos
  - std::npos is a constant meaning ‘just beyond the end of the string’…it’s a way of saying ‘Not found’
- Get a substring
  - Pass it the start character and the number of characters to copy
  - Returns a new string
- Others: replace, rfind, etc.

```
#include <iostream>
#include <string>
using namespace std;

int main(int argc, char *argv[]) {
  string s1(“abc def”);
  cout << "Len of s1: " << s1.size() << endl;

  char my_c_str[80];
  strcpy(my_c_str, s1.c_str() );
  cout << my_c_str << endl;

  if(s1.find(“bc d”) != string::npos)
    cout << “Found bc_d starting at pos=”:
    cout << s1.find(“bc_d”) << endl;

  found = s1.find(“def”);
  if( found != string::npos){
    string s2 = s1.substr(found,3)
    cout << s2 << endl;
  }
}
```

Output:

```
Len of s1: 7
abc def
The string is: abc def
Found bc_d starting at pos=1
def
```

http://www.cplusplus.com/reference/string/string/

C++ Strings

- Why do we need the string class?
  - C style strings are character arrays (char[ ])
    - See previous discussion of why we don't like arrays
  - C style strings need a null terminator ('\0')

    "abcd" is actually a ***char[5] …*** Why?
  - Stuff like this won't compile:

    char my_string[7] = "abc" + "def";
- How can strings help?
  - Easier to use, less error prone
  - Has overloaded operators like +, =, [], etc.
  - Lots of built-in functionality (e.g. find, substr, etc.)

C++ Streams

- What is a “stream”?
  - A sequence of characters or bytes (of potentially infinite length) used for input and output.
- C++ has four major libraries we will use for streams:
  - <iostream>
  - <fstream>
  - <sstream>
  - <iomanip>
- Stream models some input and/or output device
  - fstream => a file on the hard drive;
  - cin => keyboard and cout => monitor
- C++ has two operators that are used with streams
  - Insertion Operator “<<”
  - Extraction Operator “>>”

C++ I/O Manipulators

- The <iomanip> header file has a number of “manipulators” to modify how I/O behaves
    - Alignment: internal, left, right, setw, setfill
    - Numeric: setprecision, fixed, scientific, showpoint
    - Other: endl, ends, flush, etc.
    - http://www.cplusplus.com/reference/iostream/manipulators/
- Use these inline with your cout/cerr/cin statements
    - double pi = 3.1415;
    - cout << setprecision(2) << fixed << pi << endl;

Understanding Extraction

- User enters value “512” at 1st prompt, enters “123” at 2nd prompt

```
int x=0;
```

X = 0

cin =

```
cout << “Enter X: “;
```

X = 0

cin = 5 | 1 | 2 | \n

```
cin >> x;
```

X = 512

cin = \n

cin.fail() is **false**

```
int y = 0;
```

Y = 0

cin = \n

```
cout << “Enter Y: “;
```

Y = 0

cin = \n | 1 | 2 | 3 | \n

```
cin >> y;
```

Y = 123

cin = \n

cin.fail() is **false**

Understanding Extraction

- **User enters value “23 99” at 1st prompt, 2nd prompt skipped**

int x=0;	X =	0	cin =						
cout << “Enter X: “;	X =	0	cin =	2	3		9	9	\n
cin >> x;	X =	23	cin =		9	9	\n		
			cin.fail() is false						
int y = 0;	Y =	0	cin =		9	9	\n		
cout << “Enter Y: “;	Y =	0	cin =		9	9	\n		
cin >> y;	Y =	99	cin =	\n					
			cin.fail() is false						

Understanding Extraction

- **User enters value “23abc” at 1st prompt, 2nd prompt fails**

int x=0;	**X =** 0	**cin =**
cout << “Enter X: “;	**X =** 0	**cin =** `2` `3` `a` `b` `c` `\n`
cin >> x;	**X =** 23	**cin =** `a` `b` `c` `\n`

cin.fail() is false

int y = 0;	**Y =** 0	**cin =** `a` `b` `c` `\n`
cout << “Enter Y: “;	**Y =** 0	**cin =** `a` `b` `c` `\n`
cin >> y;	**Y =** `xxx`	**cin =** `a` `b` `c` `\n`

cin.fail() is true

Understanding Extraction

- **User enters value “23 99” at 1st prompt, everything read as string**

string x;

cout << “Enter X: “;

getline(cin,x);

X =   **cin =**

X =   **cin =**

2	3		9	9	\n	EOF

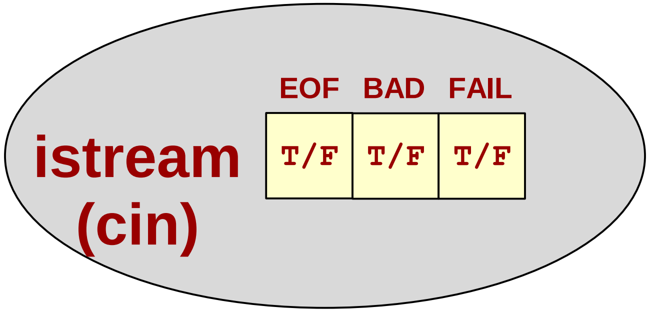
X = `23 99`   **cin =**

cin.fail() is
false

NOTE: \n character is discarded!

Understanding cin

- Things to remember
  - When a read operation on cin goes wrong, the fail flag is set
  - If the fail flag is set, all reads will automatically fail right away
  - This flag stays set until you clear it using the cin.clear() function
  - cin.good() returns true if ALL flags are false
- When you're done with a read operation on cin, you should wipe the input stream
  - Use the cin.ignore(...) method to wipe any remaining data off of cin
  - Example: cin.ignore(1000,'\n'); cin.clear();



Understanding Extraction

- **User enters value “23abc” at 1st prompt, 2nd prompt fails**

```
int y = 0;

cout << “Enter Y: “;

cin >> y;

cin.ignore(100, '\n');
// doing a cin >> here will
// still have the fail bit set
cin.clear();
// now safe to do cin >>
```

Y = 0 cin = a | b | c | \n | EOF

Y = 0 cin = a | b | c | \n | EOF

Y = xxx cin = a | b | c | \n | EOF

cin.fail() is true

cin = EOF

EOF	BAD	FAIL
0	0	1

cin = EOF

EOF	BAD	FAIL
0	0	0

C++ File I/O

- Use <fstream> library for reading/writing files
  - Use the open( ) method to get access to a file

    ofstream out; //ofstream is for writing, ifstream is for reading

    out.open(“my_filename.txt”) //must be a C style string!
- Write to a file exactly as you would the console!
  - out << “This line gets written to the file” << endl;
- Make sure to close the file when you're done
  - out.close();
- Use fail( ) to check if the file opened properly
  - out.open(“my_filename.txt”)
  - if(out.fail()) cerr << “Could not open the output file!”;

Validating User Input

- Reading user input is easy, validating it is hard
- What are some ways to track whether or not the user has entered valid input?
  - Use the fail( ) function on cin and re-prompt the user for input
  - Use a stringstream for data conversions and check the fail( ) method on the stringstream
  - Read data in as a string and use the cctype header to validate each character (http://www.cplusplus.com/reference/clibrary/cctype/)
  - for(int i=0; i < str.size(); i++)

```
  if( ! isdigit(str[i]) )
      cerr << “str is not a number!” << endl
```

C++ String Stream

- If streams are just sequences of characters, aren't strings themselves like a stream?
  - The <sstream> library lets you treat C++ string objects like they were streams
- Why would you want to treat a string as a stream?
  - Buffer up output for later display
  - Parse out the pieces of a string
  - Data type conversions
    - This is where you'll use stringstream the most!
- Very useful in conjunction with string's getline(...)

C++ String Stream

- Convert numbers into strings (i.e. 12345 => "12345")

```
#include<sstream>
using namespace std;
int main()
{
 stringstream ss;
 int number = 12345;
 ss << number;

 string strNumber;
 ss >> strNumber;

 return 0;
}
```

sstream_test1.cpp

C++ String Stream

- Convert string into numbers [same as atoi()]

```
#include<sstream>
using namespace std;
int main()
{
 stringstream ss;
 string numStr = “12345”;
 ss << numStr;


 int num;
 ss >> num;
 return 0;
}
```

sstream_test2.cpp

C++ String Stream

- Beware of re-using the same stringstream object for multiple conversions. It can be weird.
  - Make sure you clear it out between uses and re-init with an empty string
- Or just make a new stringstream each time

```
stringstream ss;

//do something with ss

ss.clear();
ss.str("");
// now you can reuse ss
// or just declare another stream
stringstream ss2;
```

C++ Arrays

- What are arrays good for?
  - Keeping collections of many pieces of the same data type (e.g. I want to store 100 integers)
  - int n[100];
- Each value is called out explicitly by its index
  - Indexes start at 0:
- Read an array value:
  - cout << “5th value = “ << n[4] << endl;
- Write an array value
  - n[2] = 255;

C++ Arrays

- Unfortunately C++ arrays can be tricky...
  - Arrays need a contiguous block of memory
  - Arrays are difficult/costly to resize
  - Arrays don't know their own size
  - You must pass the size around with the array
  - Arrays don't do bounds checking
  - Potential for buffer overflow security holes
    - e.g. Twilight Hack: http://wiibrew.org/wiki/Twilight_Hack
  - Arrays are not automatically initialized
  - Arrays can't be directly returned from a function
  - You have to decay them to pointers

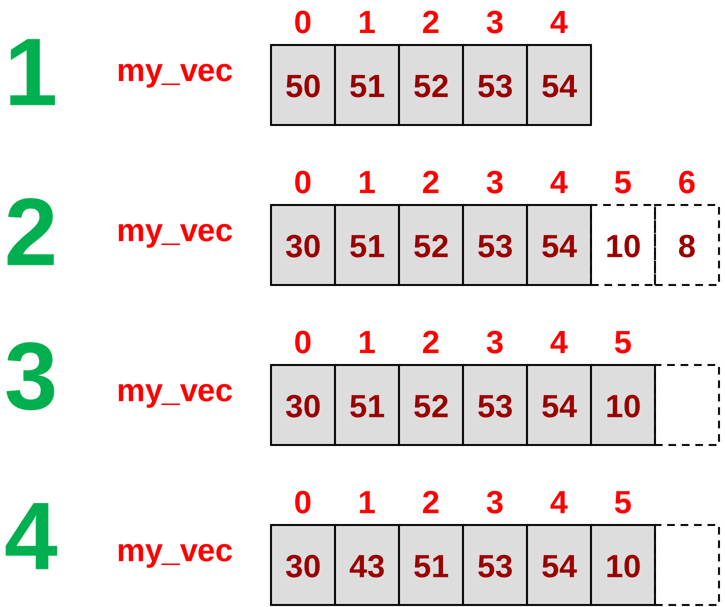
C++ Vectors

- Why do we need the vector class?
  - Arrays are a fixed size. Resizing is a pain.
  - Arrays don't know their size (no bounds checking)
  - This compiles:
    - int stuff[5];
    - cout << stuff[-1] << “ and “ << stuff[100];
- How can vectors help?
  - Automatic resizing to fit data
  - Sanity checking on bounds
  - They do everything arrays can do, but more safely
    - Sometimes at the cost of performance
  - See http://www.cplusplus.com/reference/stl/

Vector Class

- Container class (what it contains is up to you via a template)
- Mimics an array where we have an indexed set of homogenous objects
- Resizes automatically

```
#include <iostream>
#include <vector>

using namespace std;

int main()
{
  vector<int> my_vec(5); // init. size of 5
1 for(unsigned int i=0; i < 5; i++){
    my_vec[i] = i+50;
  }
  my_vec.push_back(10); my_vec.push_back(8);
2 my_vec[0] = 30;
  unsigned int i;
  for(i=0; i < my_vec.size(); i++){
    cout << my_vec[i] << “ “;
  }
  cout << endl;

3 int x = my_vec.back(); // gets back val.
  x += my_vec.front(); // gets front val.
  // x is now 38;
  cout << “x is “ << x << endl;
  my_vec.pop_back();

4 my_vec.erase(my_vec.begin() + 2);
  my_vec.insert(my_vec.begin() + 1, 43);
  return 0;
}
```



1 my_vec

0	1	2	3	4
50	51	52	53	54

2 my_vec

0	1	2	3	4	5	6
30	51	52	53	54	10	8

3 my_vec

0	1	2	3	4	5	
30	51	52	53	54	10	

4 my_vec

0	1	2	3	4	5	
30	43	51	53	54	10	

Vector Class

- constructor
  - Can pass an initial number of items or leave blank
- operator[ ]
  - Allows array style indexed access (e.g. myvec[1] + myvec[2])
- push_back(T new_val)
  - Adds a **copy** of new_val to the end of the array allocating more memory if necessary
- size(), empty()
  - Size returns the current number of items stored as an unsigned int
  - Empty returns True if no items in the vector
- pop_back()
  - Removes the item at the back of the vector (does not return it)
- front(), back()
  - Return item at front or back
- erase(*iterator*)
  - Removes item at specified index (use begin() + index)
- insert(*iterator*, T new_val)
  - Adds new_val at specified index (use begin() + index)

```
#include <iostream>
#include <vector>
using namespace std;
int main()
{
  vector<int> my_vec(5); // 5= init. size
  for(unsigned int i=0; i < 5; i++){
    my_vec[i] = i+50;
  }
  my_vec.push_back(10); my_vec.push_back(8);
  my_vec[0] = 30;
  for(int i=0; i < my_vec.size(); i++){
    cout << my_vec[i] << “ “;
  }
  cout << endl;

  int x = my_vec.back(); // gets back val.
  x += my_vec.front(); // gets front val.
  // x is now 38;
  cout << “x is “ << x << endl;
  my_vec.pop_back();

  my_vec.erase(my_vec.begin() + 2);
  my_vec.insert(my_vec.begin() + 1, 43);
  return 0;
}
```

Vector Suggestions

- If you don’t provide an initial size to the vector, you must add items using push_back()
- When iterating over the items with a for loop, used an ‘unsigned int’
- When adding an item, a copy will be made to add to the vector
- [] or at() return a reference to an element, not a copy of the element
- Usually pass-by-reference if an argument to avoid the wasted time of making a copy

```
#include <iostream>
#include <vector>

using namespace std;

int main()
{
  vector<int> my_vec;
  for(int i=0; i < 5; i++){
    // my_vec[i] = i+50; // doesn’t work
    my_vec.push_back(i+50);
  }
  for(unsigned int i=0;
      i < my_vec.size();
      i++)
  { cout << my_vec[i] << " ";   }
  cout << endl;

  my_vec[1] = 5; my_vec.at(2) = 6;

  do_something(myvec);

  return 0;
}

void do_something(vector<int> &v)
{
  // process v;

}
```