# Pointers and Memory

## An extremely powerful concept

With great power comes great responsibility

# With great power comes great responsibility

- bad pointerism can lead to
  - extremely ugly crashes
  - difficult to debug glitches
  - random crashes

Have you used pointers before?

Why have pointers?

# Have you used pointers before?

# Why have pointers?

- Pointers allow different sections of code to share information easily.
- Pointers enable complex 'linked' data structures

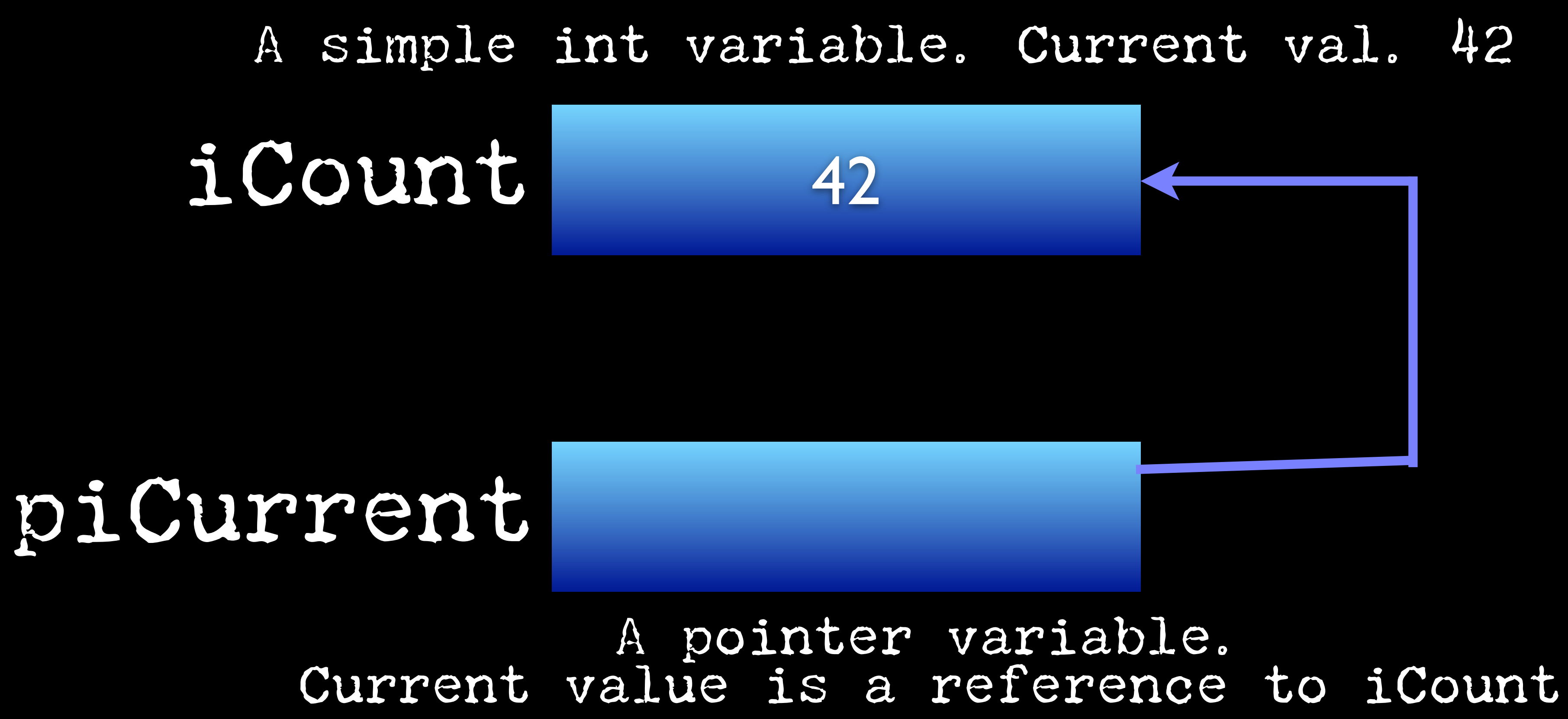
# Simple variables


An int variable is like a box which can store a single int value

# Pointers

- Don't store value directly
- Instead, stores a reference to another value (the pointee)

# pointers

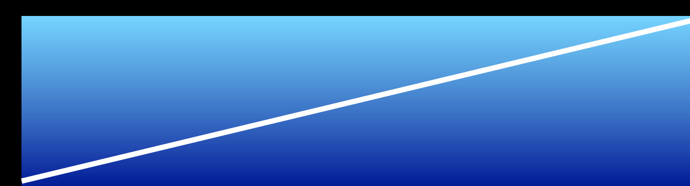

A simple int variable. Current val. 42
iCount
42
piCurrent
A pointer variable.
Current value is a reference to iCount

# The magic wand of dereferencing

How do I follow a pointer's reference to get the value of the pointee?

# The null potion

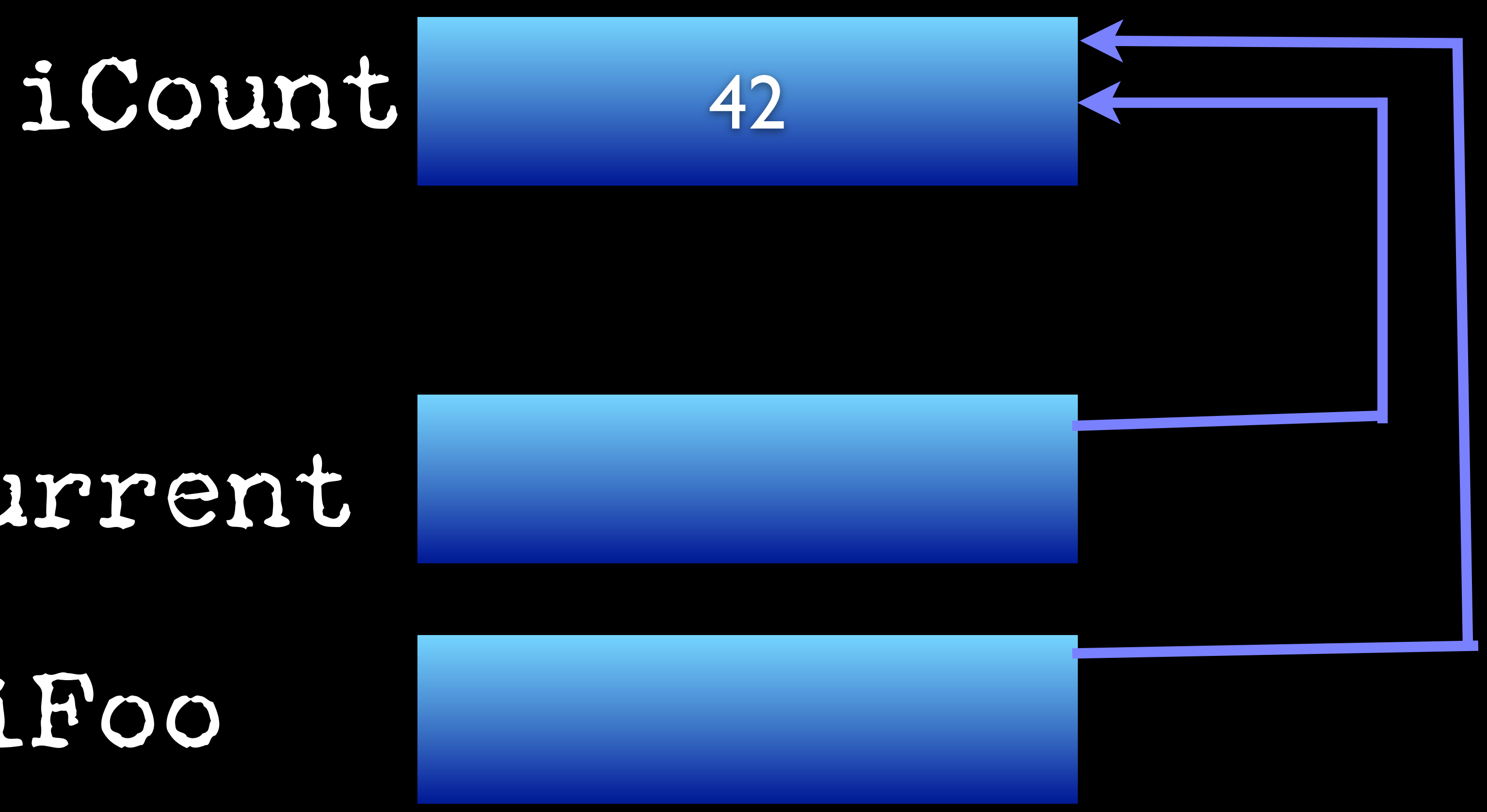
How do I point to nothing?

piCurrent 

C:    NULL (constant 0)
C++:  0
Java: null

# The magic wand of pointer assignment

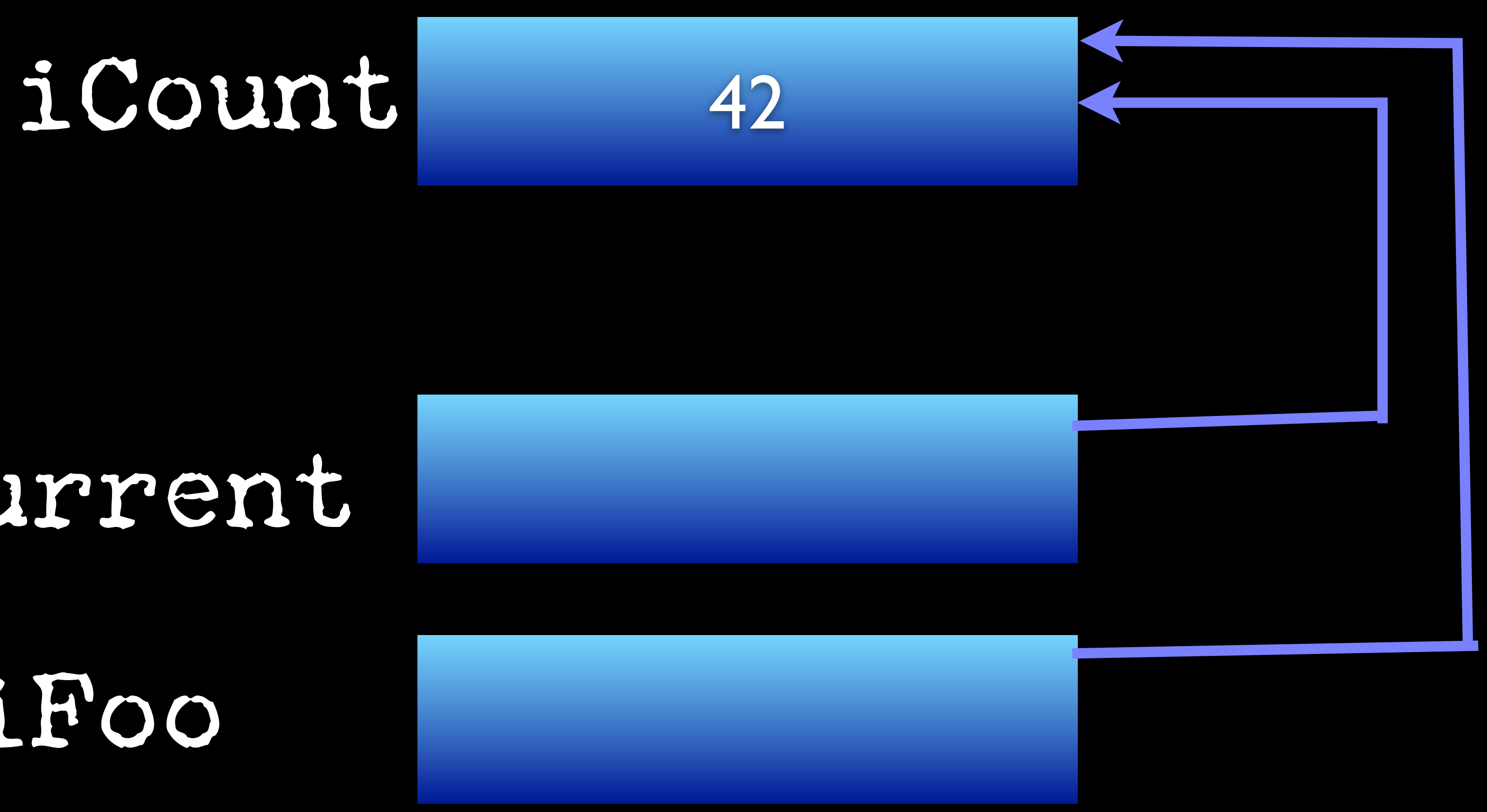
- The assignment operator (=) between 2 pointers makes them point to the same pointee.




piFoo = piCurrent

# SHARING:
# two pointers referring to a single pointee are said to be sharing.

2 entities share a single memory structure



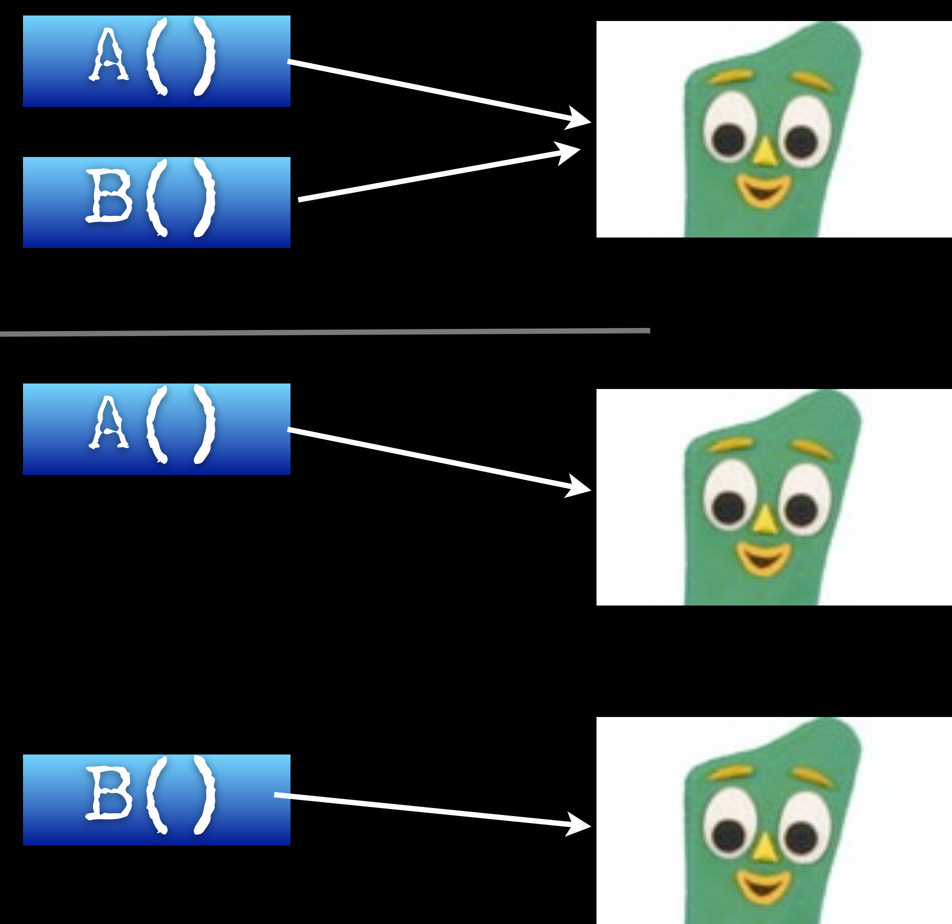

piFoo = piCurrent

# Shallow and Deep Copying

- How do functions pass values?

Shallow/Sharing

Deep/Copying



# Bad pointers

- Every pointer starts off bad.
- Must use magic to make it "good"

piFoo @*&*%$

- Bad pointer errors are very common.

# Bad pointers

- Every pointer starts off bad.
- Must use magic to make it "good"


- In the video, this caused Blinky to explode.

# Bad pointers

- In C pointers are inherently bad.
- In Java, Perl, and Lisp pointers are inherently good (set to null)

That's everything conceptually you need to know about pointers

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1. the pointer must be allocated

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1. the pointer must be allocated
2. the pointee must be allocated

That's everything conceptually you need to know about pointers

1. the pointer must be allocated
2. the pointee must be allocated
3. the pointer must be assigned to point to the pointee

That's everything conceptually you need to know about pointers

1. the pointer must be allocated
2. the pointee must be allocated
3. the pointer must be assigned to point to the pointee
4. people rarely screw up (1)

That’s everything conceptually you need to know about pointers

<syntax>

# Syntax

- A pointer type in C is just the pointee type followed by *

```
int *
float *
char *
```

# Syntax

- A pointer type in C is just the pointee type followed by *

```
int *
float *
char *
```

# Variables

```
int * piFoo; /* starts off bad */
```

allocates space for the pointer
but not the pointee
pointer starts out "bad"

# The & operator (reference to)

```
void numPtrExample() {
   int iCount;
   int* piFoo;

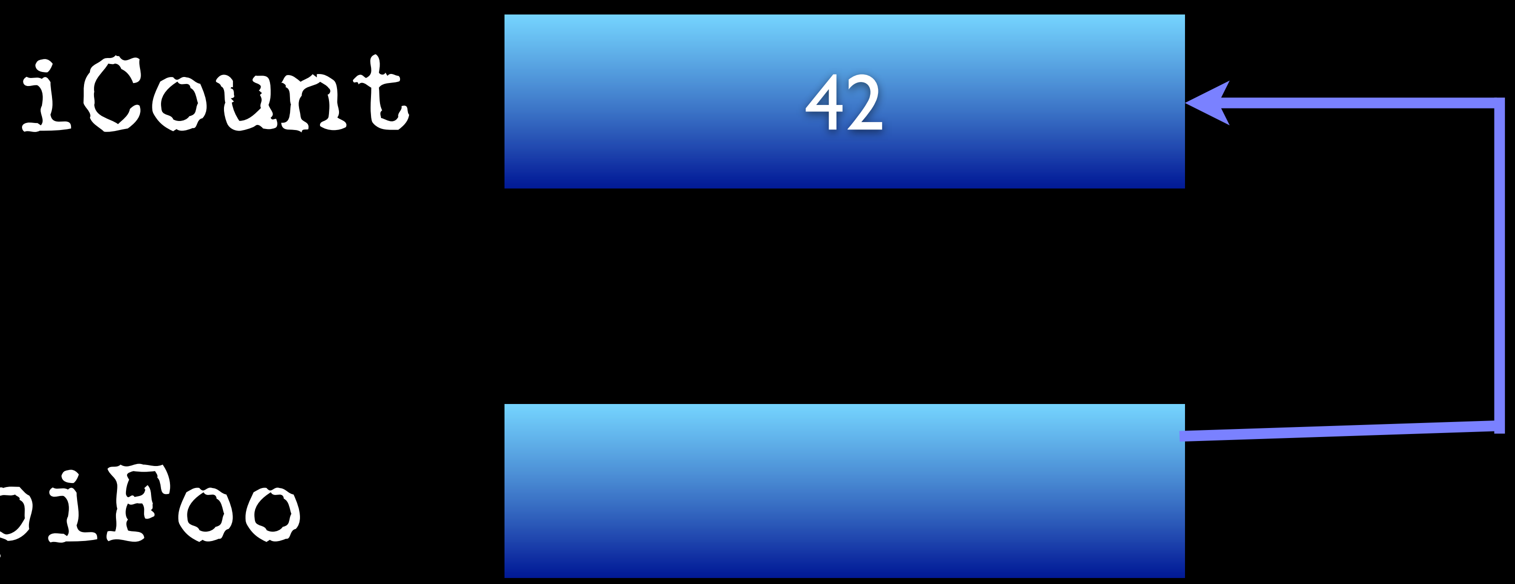
   iCount = 42
   piFoo = &iCount;
```

The & computes a reference to the variable

# The & operator (reference to)

```
void numPtrExample() {
   int iCount;
   int* piFoo;

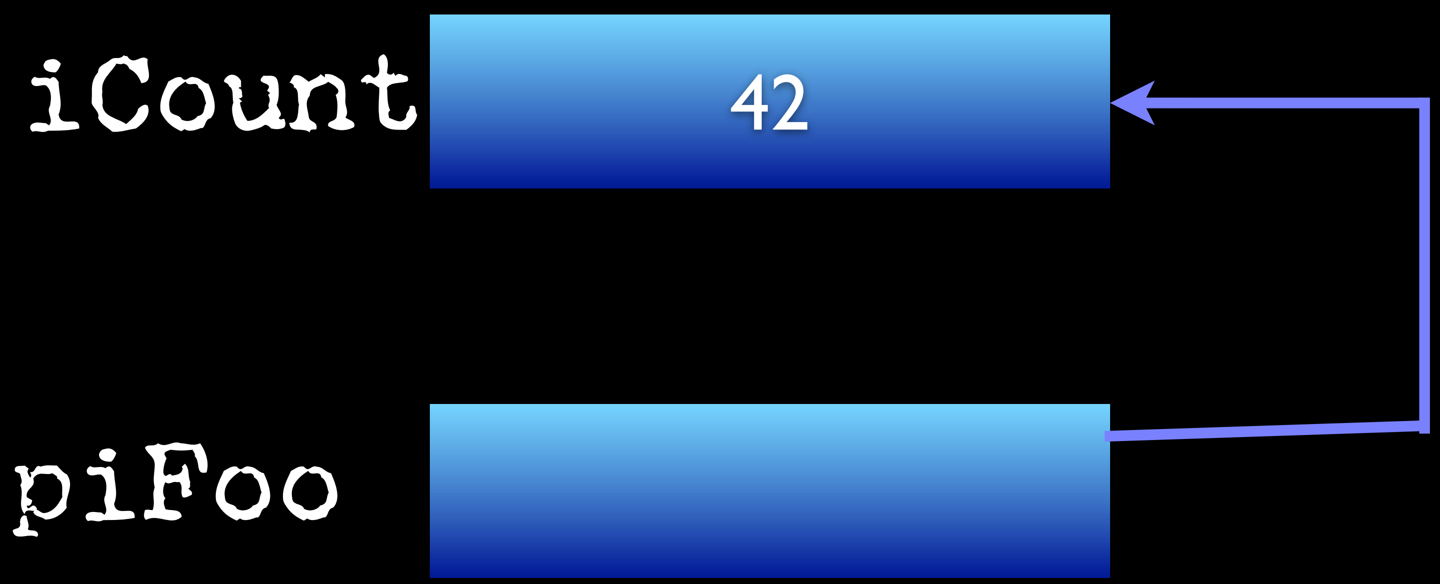
   iCount = 42
   piFoo = &Count;
```



# The & operator (reference to)

It is possible to use & in a way that compiles fine but creates a problem @ run time....

more on this later

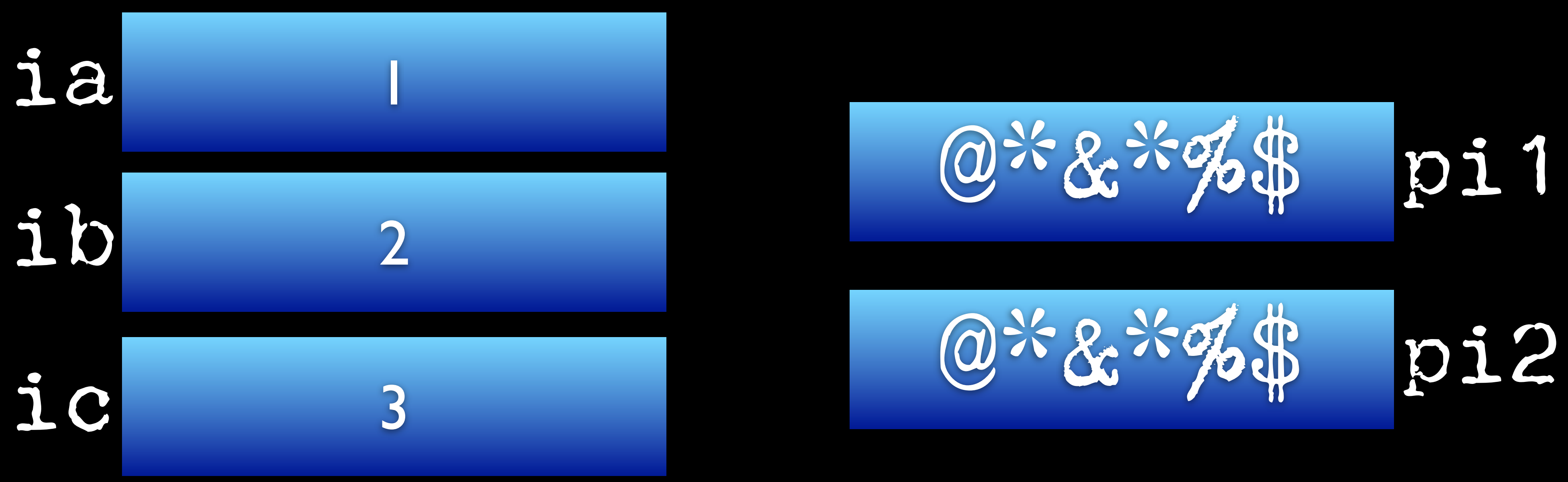


# The * operator dereferences

```
void pointerTest() {
  int ia = 1;
  int ib = 2;
  int ic = 3;
  int* pi1;
  int* pi2;
```

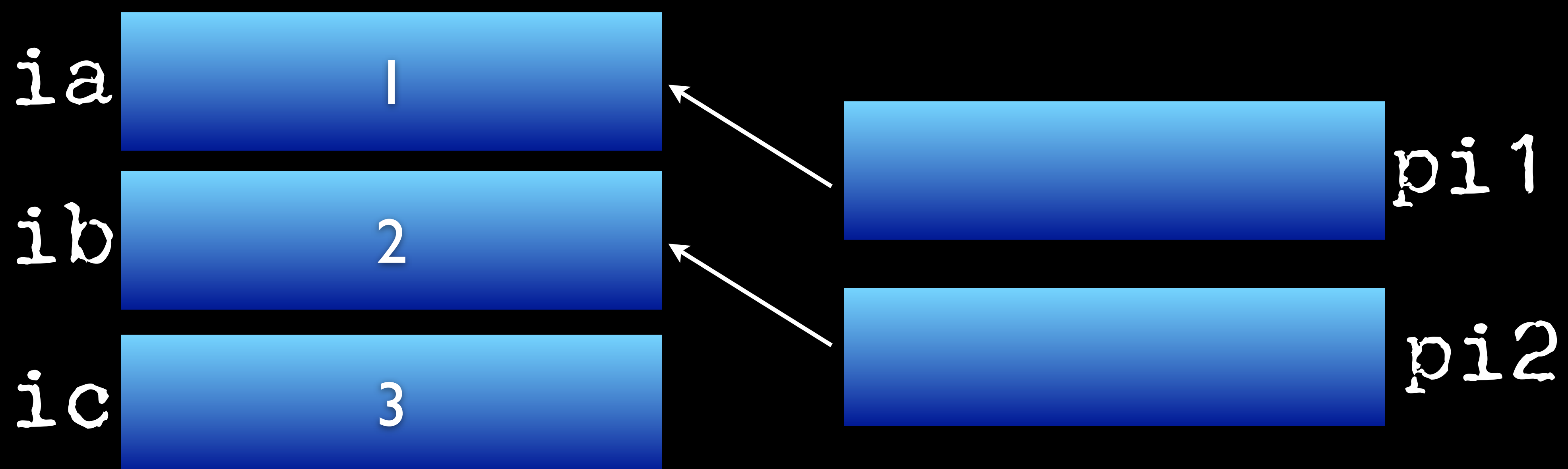
# The * operator dereferences

```
void pointerTest() {
   int ia = 1;
   int ib = 2;
   int ic = 3;
   int* pi1;
   int* pi2;
```



# The & operator provides a reference to

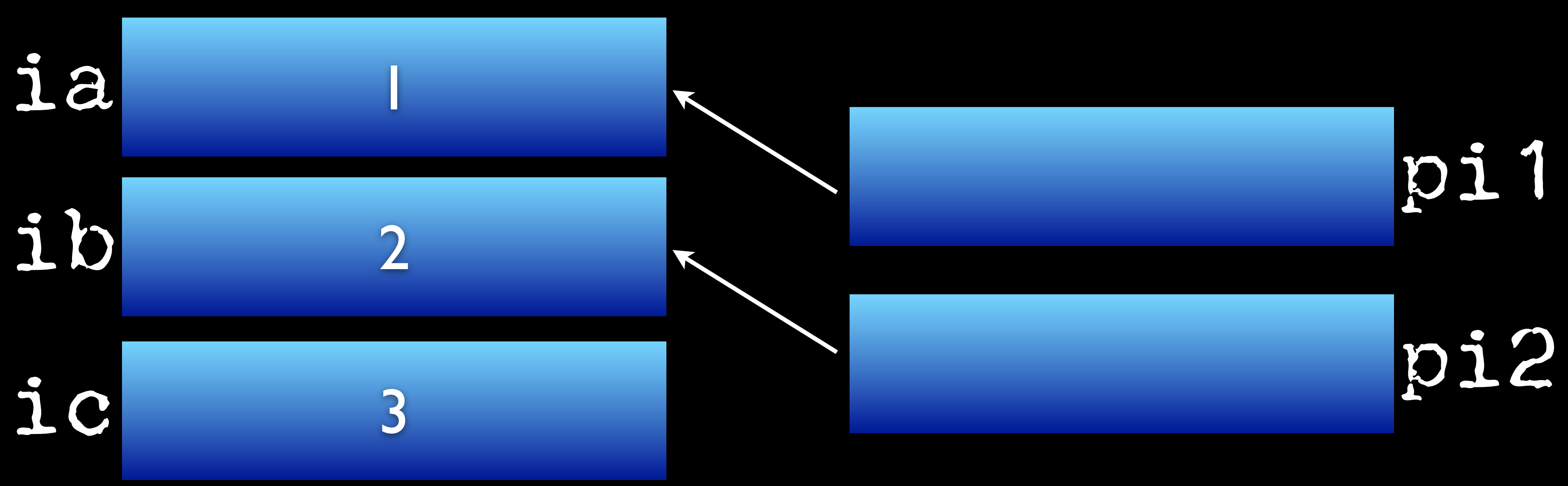
```
pi1 = &ia;
pi2 = &ib;
```



# The * operator dereferences

```
pi1 = &ia;
pi2 = &ib;

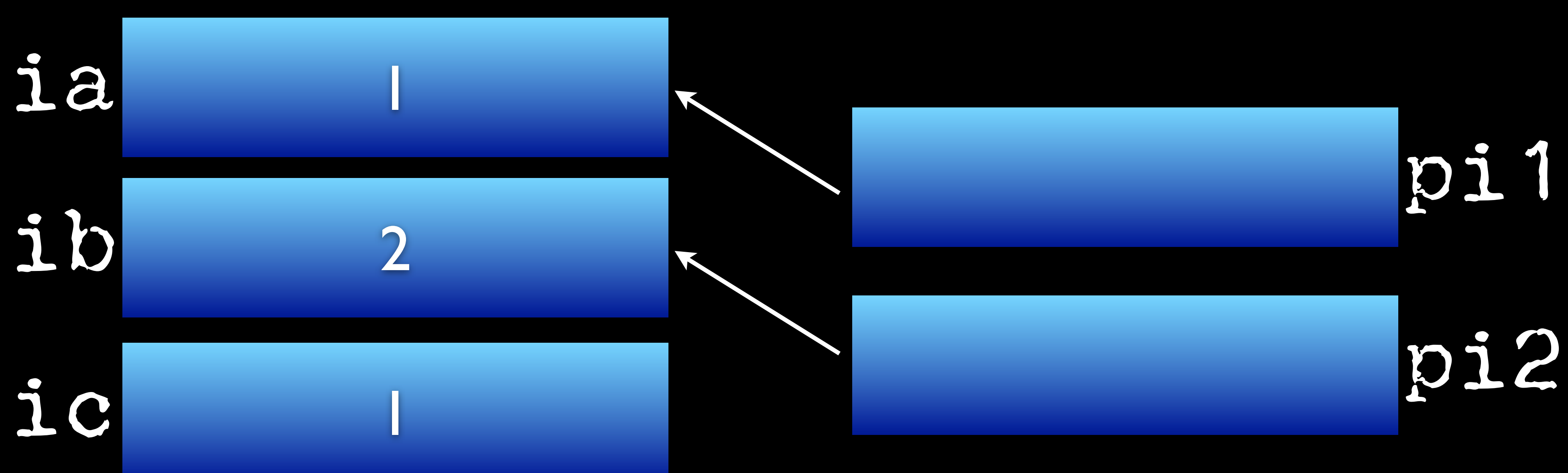
ic = *pi1; /* what does this do?*/
```



# The * operator dereferences

```
pi1 = &ia;
pi2 = &ib;

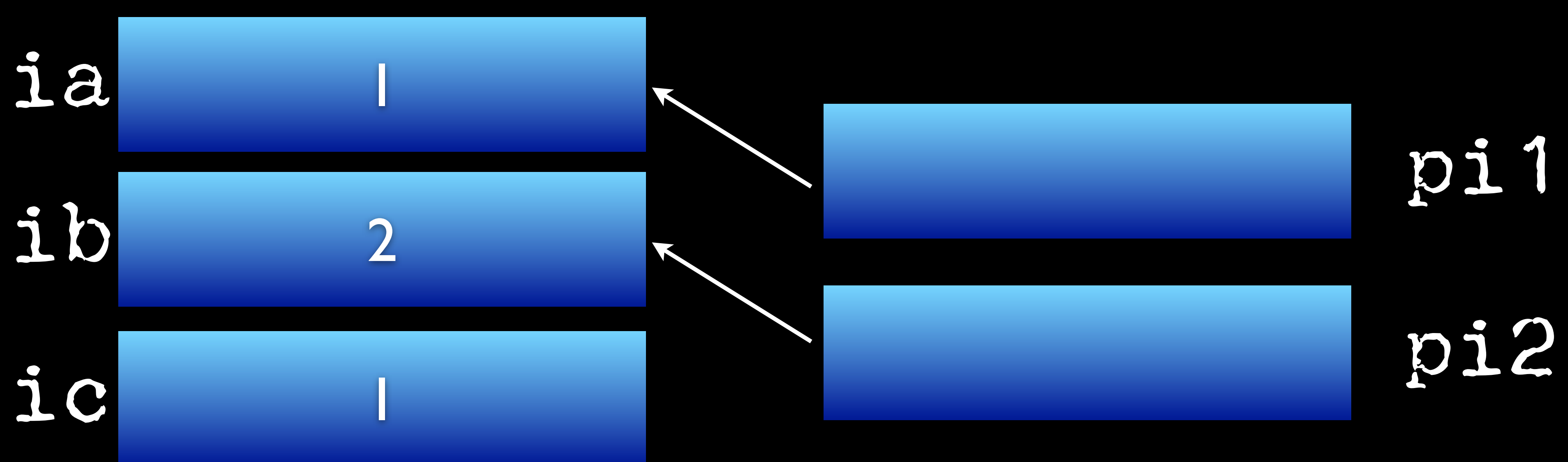
ic = *pi1;   /* what does this do?*/
```



# The * operator dereferences

```
pi1 = &ia;
pi2 = &ib;

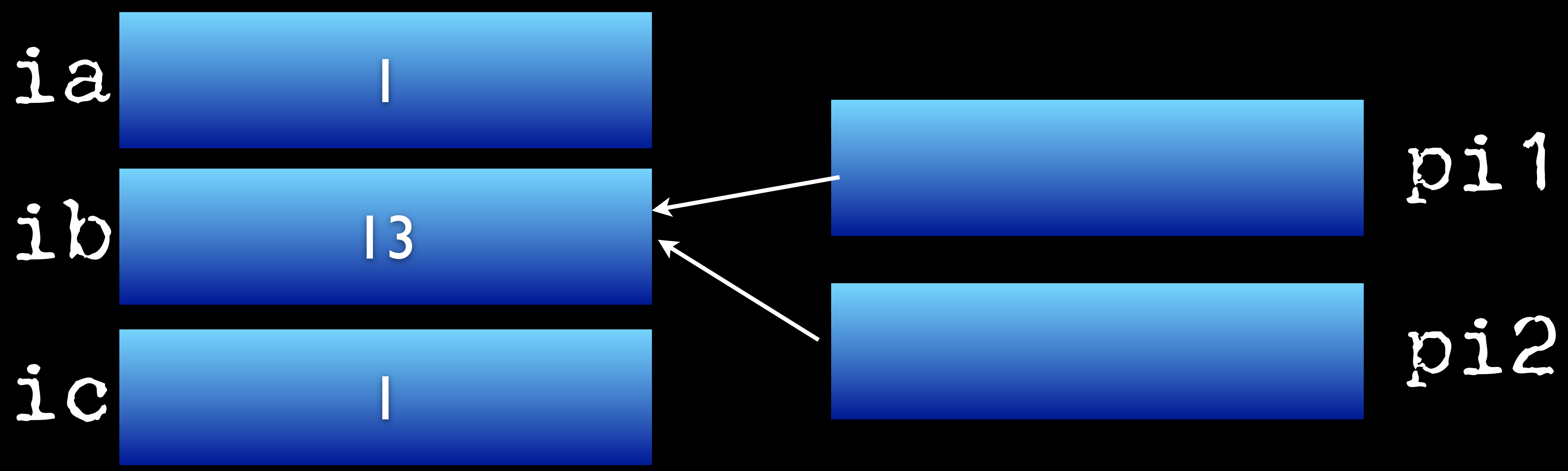
ic = *pi1;
pi1 = pi2;
*pi1 = 13;        /* ???? */
```



# The * operator dereferences

```
pi1 = &ia;
pi2 = &ib;

ic = *pi1;
pi1 = pi2;
*pi1 = 13;
```

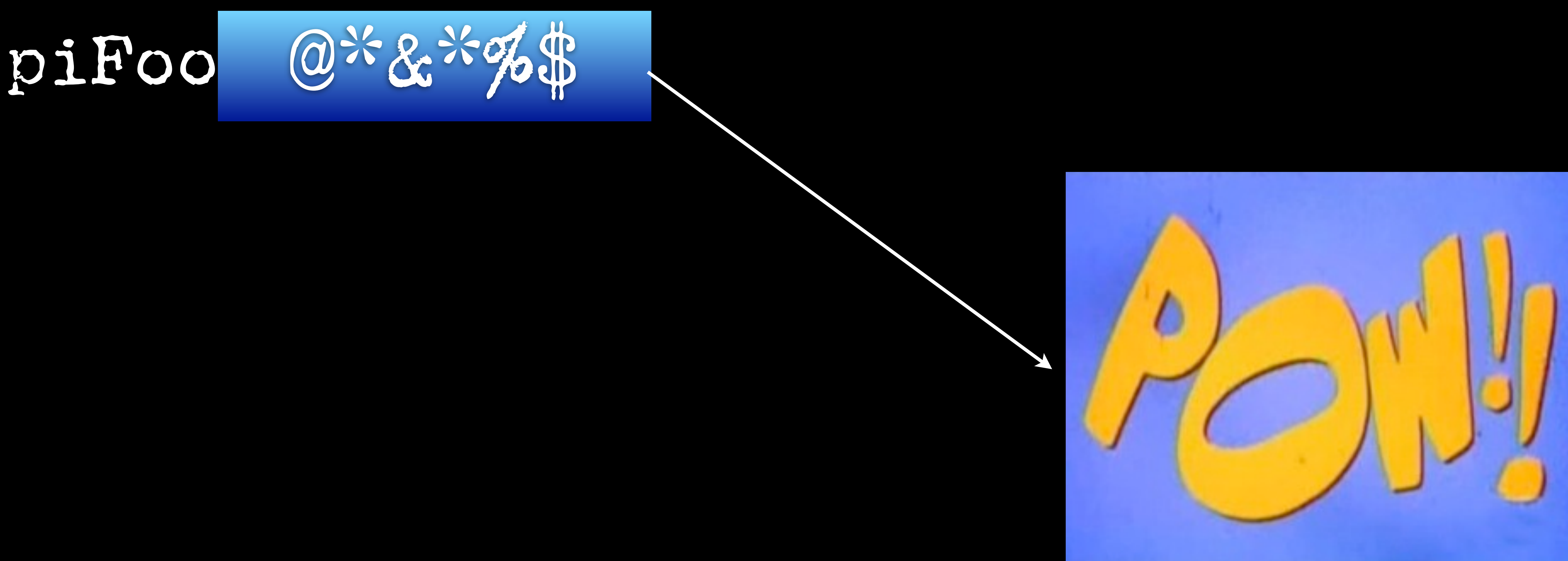


# Another example

```
void pointerEx2() {
   int* piFoo;
   *piFoo = 42;
   }
```

# Another example

```
void pointerEx2() {
   int* piFoo;
   *piFoo = 42;
   }
```



# Summary

- A pointer stores a reference to its pointee. The pointee, in turn, stores something useful.

# Summary

- The dereference operation on a pointer accesses its pointee.
- A pointer may only be dereferenced after it has been assigned to refer to a pointee.
- Most pointer bugs involve violating this rule.

# Summary

- Allocating a pointer does not automatically assign it to refer to a pointee.
- Assigning the pointer to refer to a specific pointee is a separate operation which is easy to forget.

# Summary

- Assignment between two pointers makes them refer to the same pointee which introduces sharing.

# <Local Memory>

Everyone uses _______________
but no one thinks about them.

Everyone uses local variables
but no one thinks about them.

# You have a bunch of local variables in your code

```
int ilength;
int isum;
float fFrequency;
int itotal;
int iItemsSold;
```

All these represent space in computer memory

# You have a bunch of local variables in your code

```
int ilength;
int isum;
float fFrequency;
int itotal;
int iItemsSold;
```

All these represent space in computer memory

It's not the case that every variable in a program has a permanently assigned area of memory

# You have a bunch of local variables in your code

```
int ilength;
int isum;
float fFrequency;
int itotal;
int iItemsSold;
```

Modern compilers are smart enough to give memory to a variable only when necessary

The terminology is allocate and deallocate

The most common memory related error is using a deallocated variable.

# Local Memory

```
int Square(int inum) {
   int iresult;
   iresult = inum * inum;
   return iresult;
   }
```

When the square function runs, memory is allocated for inum and iresult.

When the function exits, the storage is deallocated.

```
void Foo(int ifoo) {
     int i;
     float fScores[100];
     ifoo = ifoo + 1;
     for (i = 0; i < ifoo; i++)
     {
       Bar(i + ifoo);
     }

     }
```

ifoo, i, fScores, allocated when Foo runs.

These variables continue to exist within the for loop.

They continue to exist even during calls to other fns.

The locals are deallocated when the fn. exits a slightly more complex example

```
void X() {
    int ifoo = 1;
    int ibar = 2;
    // T1

    Y(ifoo);
    // T3

    Y(ibar);
    //T5
    }

void Y(int iarg)
{
  int isum;
  isum = iarg + 2;
  //T2 (1st time) T4 (2nd)
}
```

```
void X() {
  int ifoo = 1;
  int ibar = 2;
  // T1

  Y(ifoo);
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void X() {
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  // T1

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  //T5
  }


void Y(int iarg)
{
  int isum;
  isum = iarg + 2;
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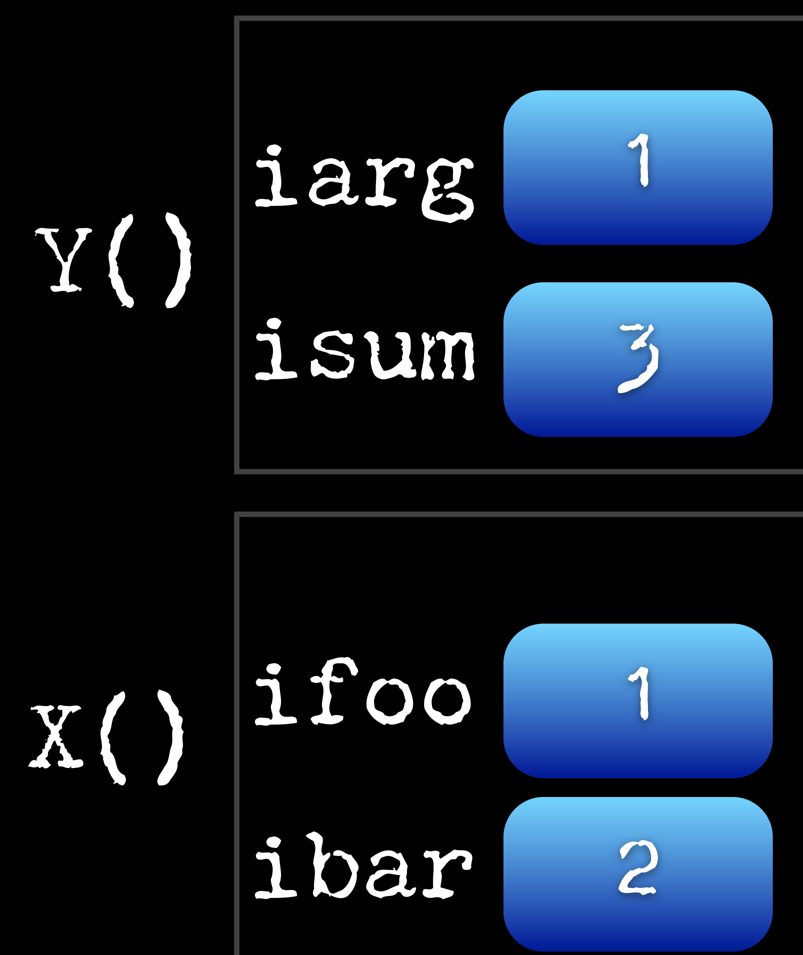
}
```

# T2



```
void X() {
  int ifoo = 1;
  int ibar = 2;
  // T1

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  // T3

  Y(ibar);
  //T5
  }


void Y(int iarg)
{
  int isum;
  isum = iarg + 2;
  //T2 (1st time) T4 (2nd)
}
```

T3

T4

```
void X() {
  int ifoo = 1;
  int ibar = 2;
  // T1

  Y(ifoo);
  // T3

  Y(ibar);
  //T5
  }


void Y(int iarg)
{
  int isum;
  isum = iarg + 2;
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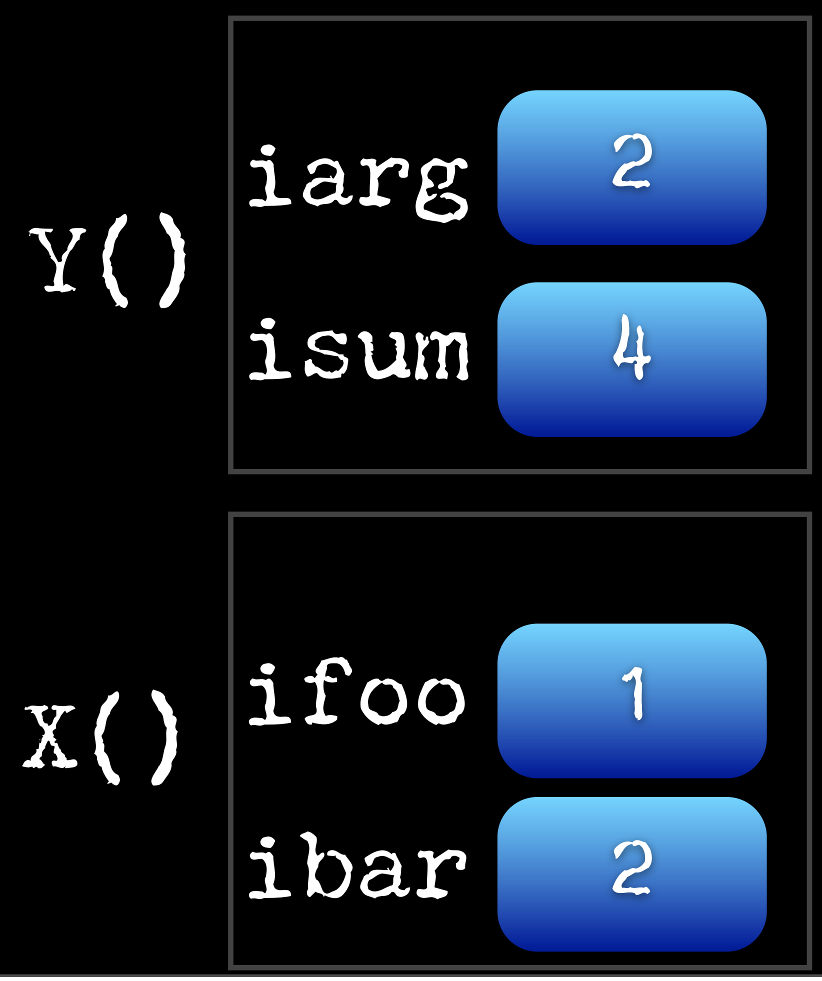
}
```



```
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  // T3

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  //T5
  }


void Y(int iarg)
{
  int isum;
  isum = iarg + 2;
  //T2 (1st time) T4 (2nd)
}
```

# Advantages of Locals

- Convenient- fns. usually need temp. memory.
- efficient - allocating and deallocating fast
- local copies - maintains independence

# Disadvantages of Locals

- Short lifetime - sometimes want things to last beyond life of fn.
- Restricted Communication (flipside of independence)

# Example

```
// Returns pointer to int
int * piMakeNode() {
    int itemp = 0;
    return (&itemp);

  }

  void  Victim() {
   int * piFoo;
   piFoo = piMakeNode();
   *ptr = 42;

  }
```

# Example

```
// Returns pointer to int
int * piMakeNode() {
    int itemp = 0;
    return (&itemp);

  }

  void  Victim() {
   int * piFoo;
   piFoo = piMakeNode();
   *ptr = 42;

  }
```

Is there a problem?

# Comment on This Example

```
int ifactorial(int i) {
    int inum;
    inum = i * ifactorial(i - 1);
    return inum;
}

int  main() {
 int inumber;
 inumber = ifactorial(5);
 printf("num %d\n",inumber);
}
```

Predictions? Show demo

# Example

```
int ifactorial(int i) {
    int inum;
    inum = i * ifactorial(i - 1);
    return inum;
}

int  main() {
 int inumber;
 inumber = ifactorial(5);
 printf("num %d\n",inumber);
}
```

Stack Overflow Error
Segmentation Fault

<reference parameters>

# Caller-Callee Communication

- Caller can pass info to callee using parameters and local variables.
- Callee can pass info to caller only through return values
- This might be too limited.

# Bill Gates Net Worth

```
int iB(int iworth) {
   iworth = iworth + 1;
   // T2
}

int  iA() {
 int inetWorth;
 inetWorth = 56; //T1
 iB(inetWorth);
 // T3
}
```

# Bill Gates Net Worth

```
int iB(int iworth) {
   iworth = iworth + 1;
   // T2
}

int  iA() {
 int inetWorth;
 inetWorth = 56; //T1
 iB(inetWorth);
 // T3
}
```

T1

iA() inetWorth 56

# Bill Gates Net Worth

```
int iB(int iworth) {
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   // T2
}

int  iA() {
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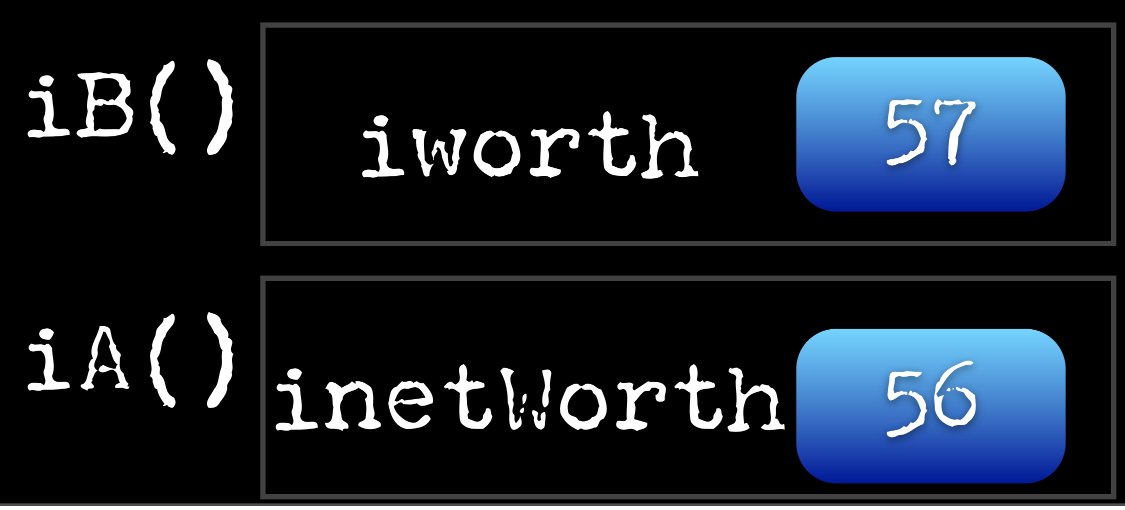
 // T3
}
```

T2



# Bill Gates Net Worth

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int iB(int iworth) {
   iworth = iworth + 1;
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}

int  iA() {
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 iB(inetWorth);
 // T3
}
```

T3

iA() inetWorth 56

# What we want ...

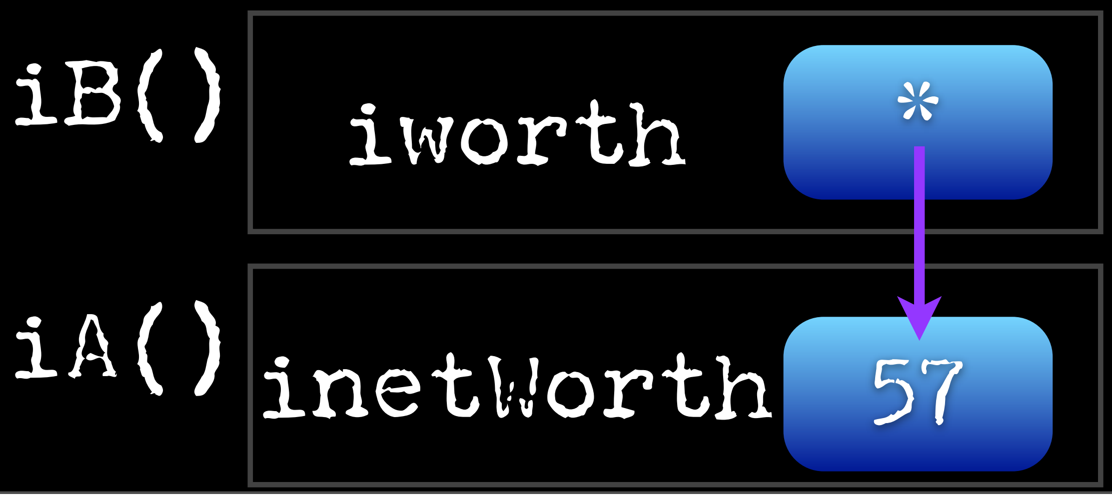
T1

iA() inetWorth 56

# What we want ...

Instead of a copy, iB() receives a pointer to inetWorth. iB() dereferences the pointer to access and change inetWorth.

T2



# What we want ...

T3

iA() | inetWorth 57

# What do we change to do that?

```
int iB(int iworth) {
   iworth = iworth + 1;
   // T2
}

int  iA() {
 int inetWorth;
 inetWorth = 56; //T1
 iB(inetWorth);
 // T3
}
```

T3

iA() | inetWorth | 57

# What do we change to do that?

```
int iB(int * piworth) {
    iworth = iworth + 1;
    // T2
}

int  iA() {
  int inetWorth;
  inetWorth = 56; //T1
  iB(&inetWorth);
  // T3
}
```

T3

iA() inetWorth 57

# What do we change to do that?

```
int B(int * worth) {
   worth = worth + 1;
   // T2
}

int  A() {
 int netWorth;
 netWorth = 56; //T1
 B(&netWorth);
 // T3
}
```

T3

A() | netWorth | 57

# What do we change to do that?

```
int B(int * worth) {
   worth = worth + 1;
    // T2
}

int  A() {
 int netWorth;
 netWorth = 56; //T1
 B(&netWorth);
 // T3
}
```

T3

# Using pointers avoids making copies

- efficient. (e.g. arrays)
- unclear which copy is correct

A person with one watch always knows what time it is. A person with two is never sure.

# Swap - you try

```
int  main() {
 int ix = 6;
 int iy = 15;
 swap(&ix, &iy);
}
```

# Swap - you try

```
void swap(int * pia, int * pib) {
  int temp;
  temp = *a;
  *a = *b;
  *b = temp;
}


int  main() {
 int ix = 6;
 int iy = 15;
 swap(&ix, &iy);
}
```

# <Heap Memory>

aka dynamic memory

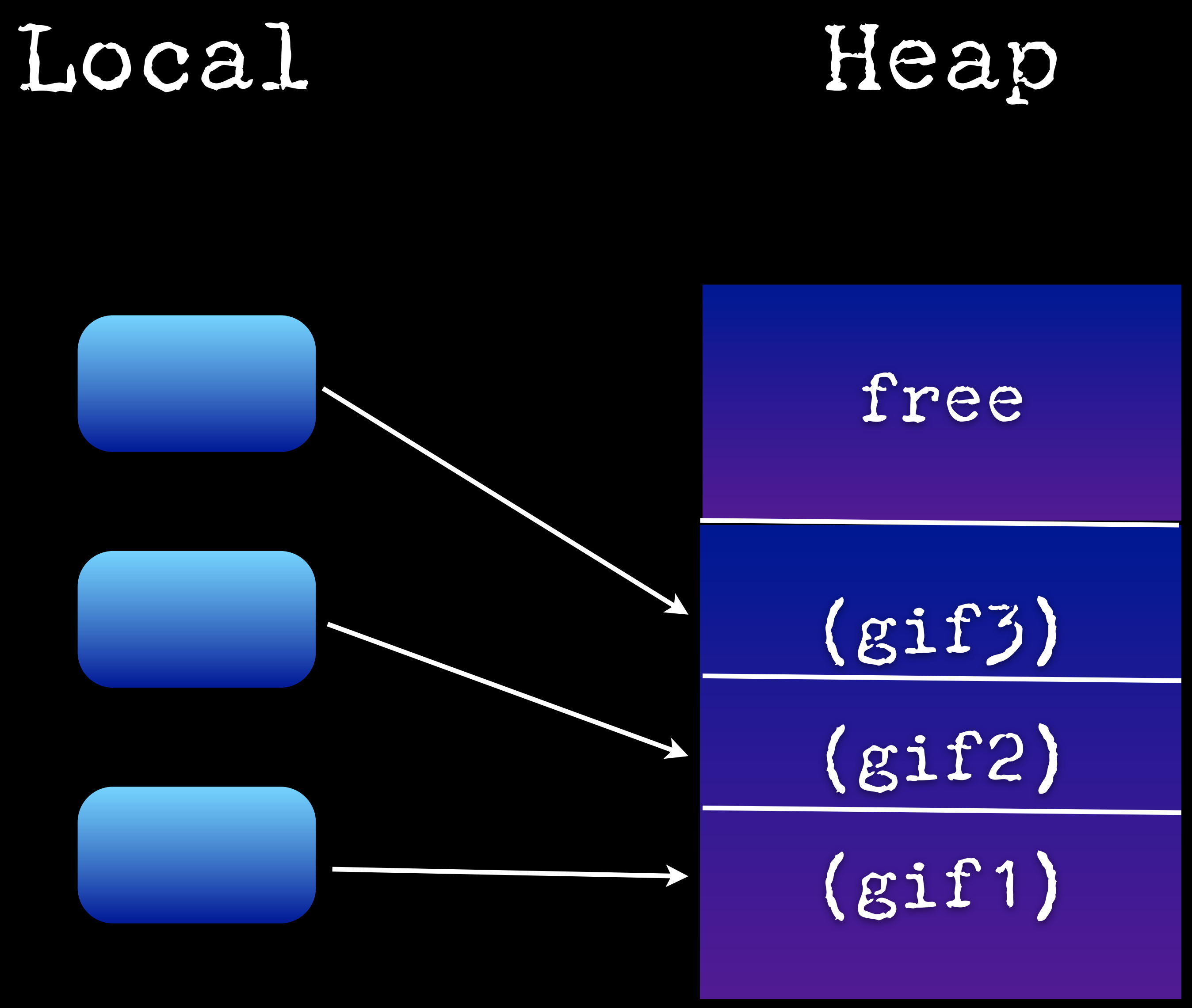
# Advantages

- lifetime: can build sth. in function and return it.
- size: can control memory allocation precisely. (e.g., estimating array sizes)

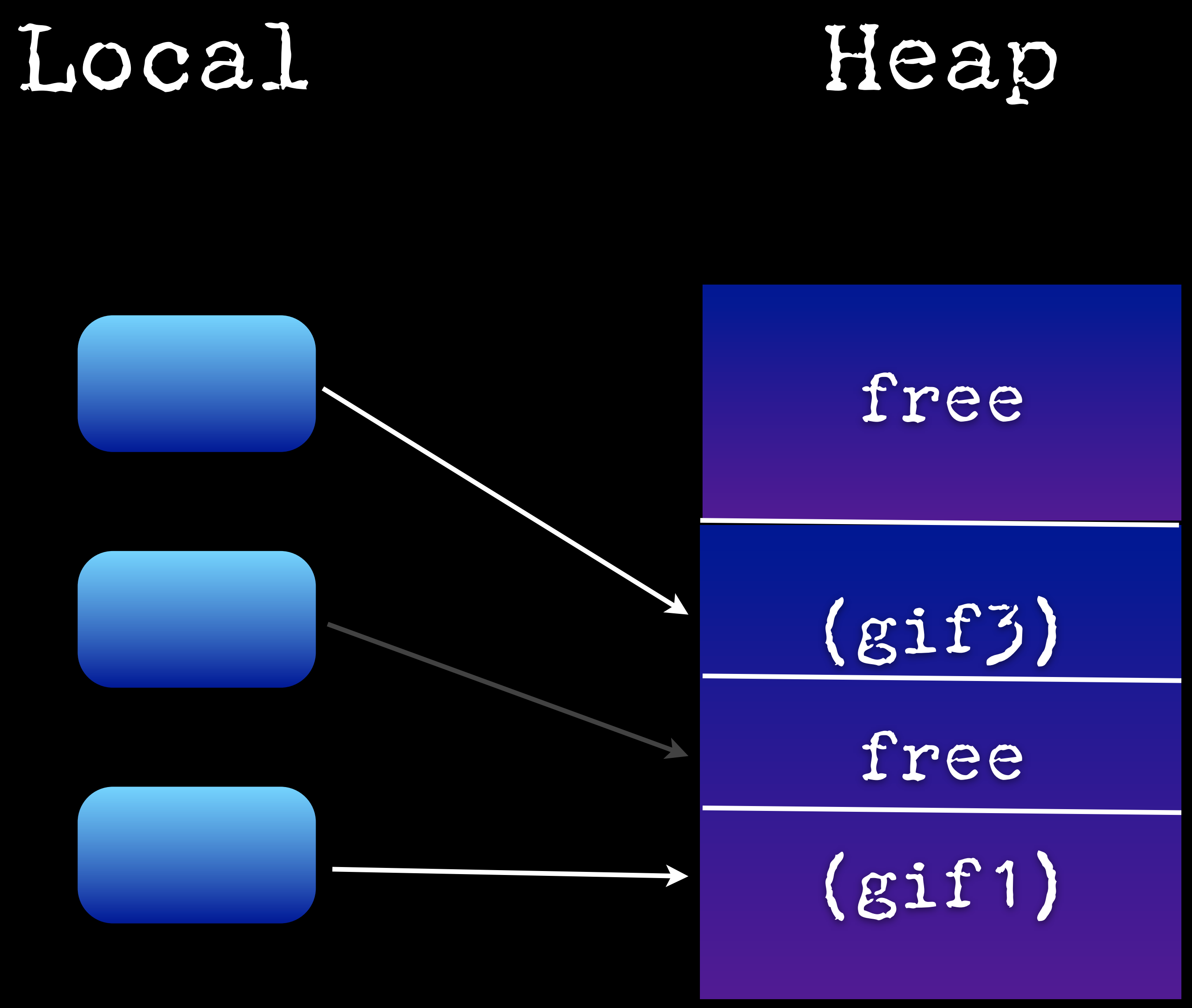
# Disadvantages

- more work
- more bugs

# Heap -- allocation



# Heap -- deallocation



# C Specifics

- `void * malloc(unsigned long size)` returns a pointer to a new heap block of the requested size. it returns NULL if it cannot allocate due to heap being full.

# C Specifics

- void free(void* heapBlockPointer) takes a pointer to a heap block and returns the block to the free pool for later reuse
- Malloc and free should be balanced.

# Simple example

```
int  iHeap1() {
 int *piFoo;

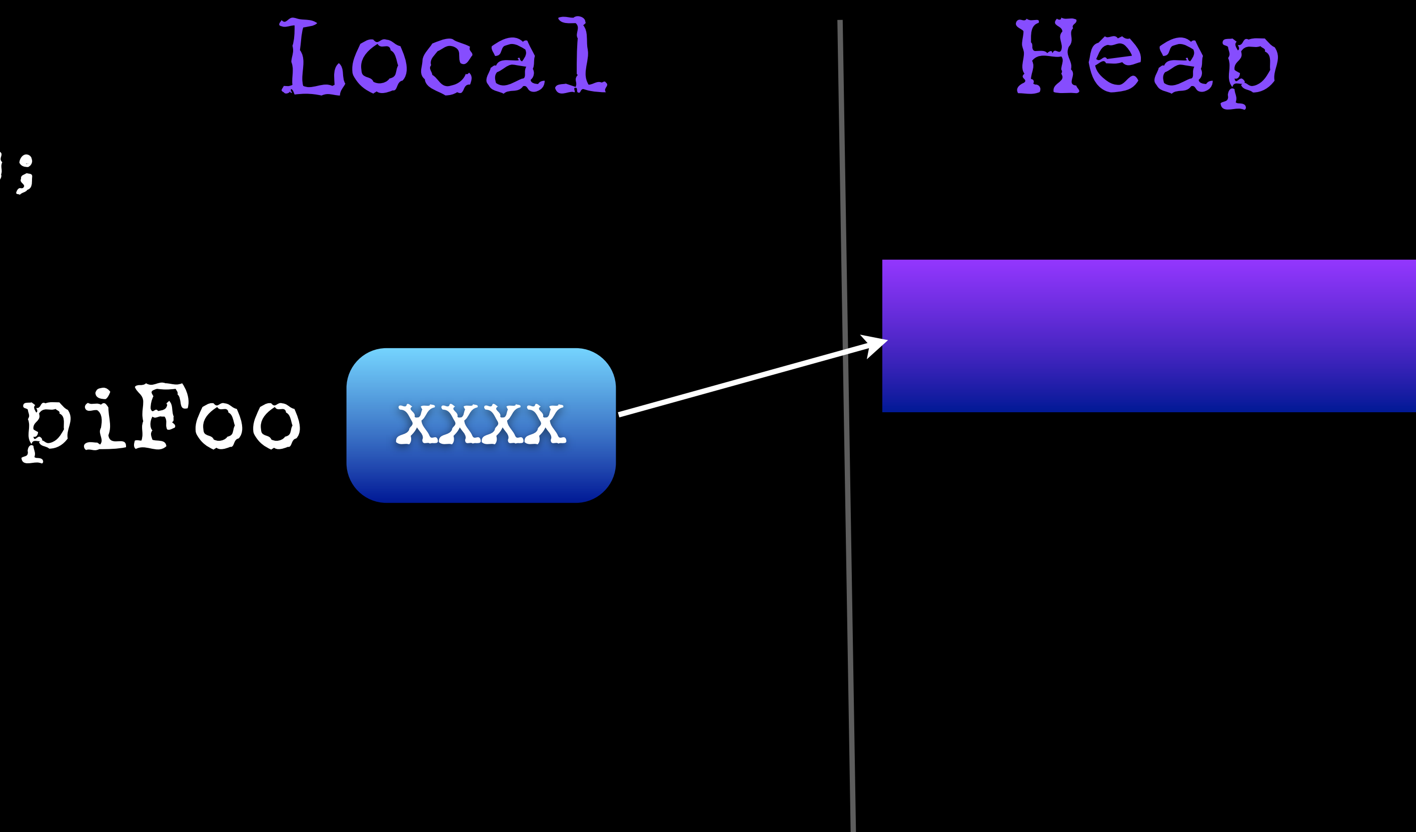


}
```

# Simple example

```
int  iHeap1() {
 int *piFoo;
 piFoo = malloc(sizeof(int);

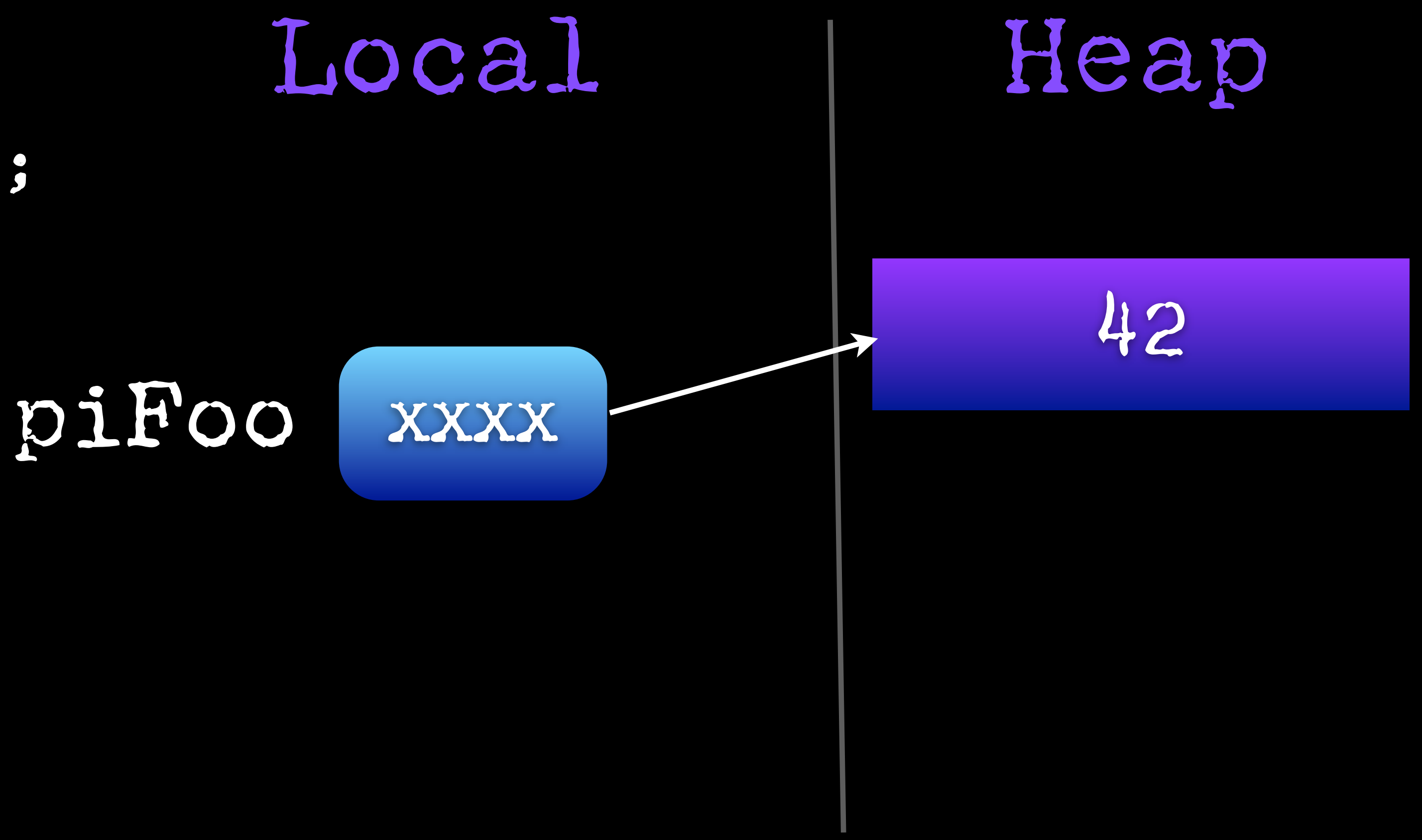

}
```



# Simple example

```
int  oHeap1() {
 int *piFoo;
 piFoo = malloc(sizeof(int);
 *piFoo = 42;


}
```



# Compare

```
int * iCreateInt(int ix) {
 int *piFoo;
 piFoo = malloc(sizeof(int);
 *piFoo = ix;
 return piFoo;

}
```

```
int * iCreateInt2(int ix) {
 int itmp;
 itmp = ix;
 return &itmp;

}
```

# Memory leaks

- memory on the heap is allocated but never deallocated.
- For small, short-lived programs this is not a problem.
- They are a problem for programs that run an indeterminate amount of time. (for ex., OSs)

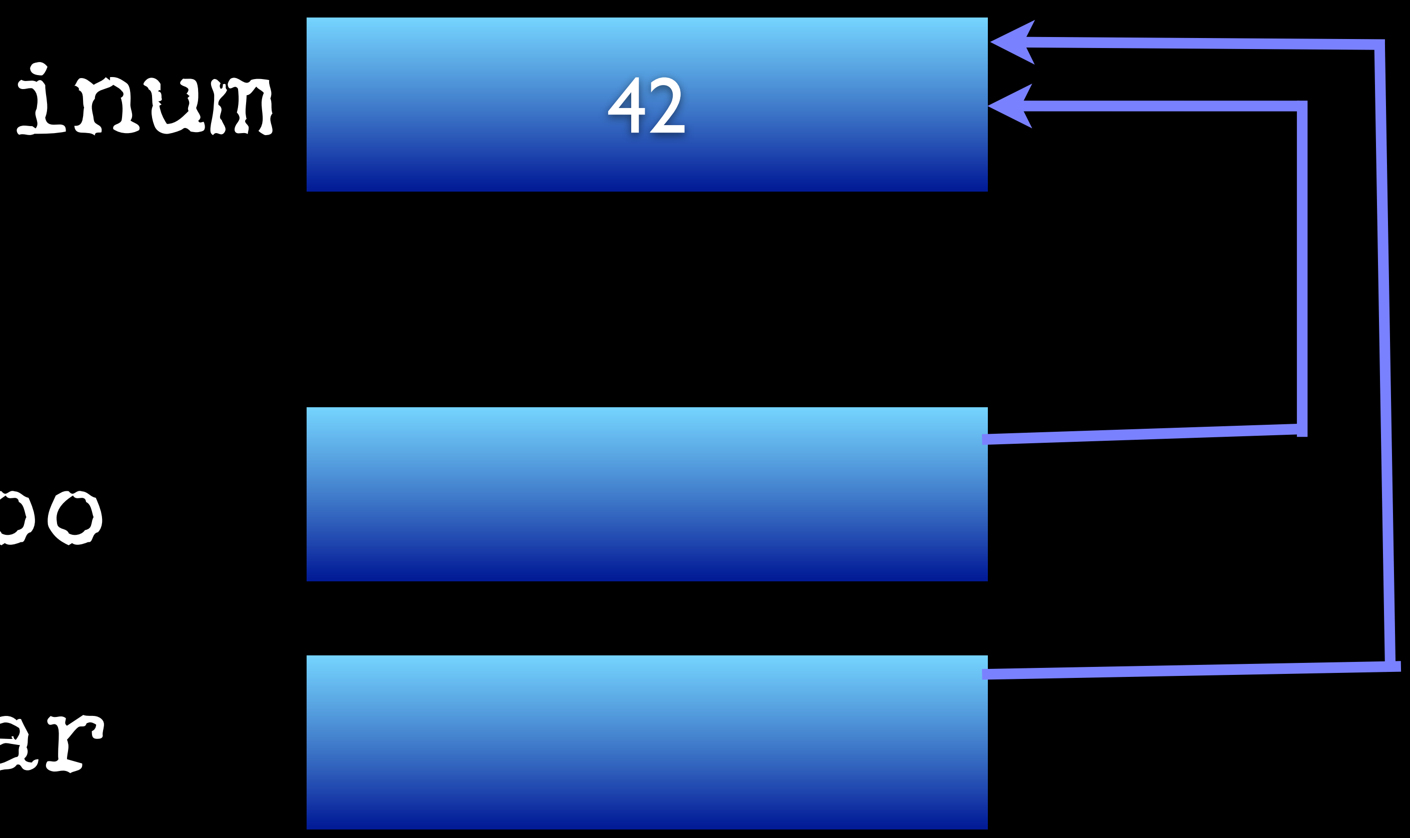
# Memory leaks

- Many commercial programs have memory leaks.
- When they run for long enough they fill up the heap and crash.
- Firefox 2,

<one last thing>

# The magic wand of pointer assignment

- The assignment operator (=) between 2 pointers makes them point to the same pointee.




piBar = piFoo

# One last thing ...

```
int main()
{
    struct node * pnodeList;
    struct node * pnodeHead = NULL;
    pnodeList = pnodeMakeShortList();
    printList(pnodeList);
    pnodeAddFront(pnodeList, 77);
    printList(pnodeList);
```

# One last thing . . .

```
void pnodeAddFront(struct node * pnodeAlist, int ix)
{
      struct node * pnodetmp;
      pnodetmp = (struct node *) malloc(sizeof(struct node));
      pnodetmp->next = pnodeAlist;
      pnodetmp->data = ix;
      pnodeAlist = tmp;
      printList(pnodeAlist);
}


int main()
{
    struct node * pnodeList;
    struct node * pnodeHead = NULL;
    pnodeList = pnodeMakeShortList();
    printList(pnodeList);
    pnodeAddFront(pnodeList, 77);
    printList(pnodeList);
```

```
Macintosh-2:Desktop $ ./a.out
Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
Data: 77  Next: 0x100120
Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
WHAT IS YOUR PREDICTION?
```

# One last thing . . .

```
void pnodeAddFront(struct node * pnodeAlist, int ix)
{
      struct node * pnodetmp;
      pnodetmp = (struct node *) malloc(sizeof(struct node));
      pnodetmp->next = pnodeAlist;
      pnodetmp->data = ix;
      pnodeAlist = tmp;
      printList(pnodeAlist);
}


int main()
{
    struct node * pnodeList;
    struct node * pnodeHead = NULL;
    pnodeList = pnodeMakeShortList();
    printList(pnodeList);
    pnodeAddFront(pnodeList, 77);
    printList(pnodeList);
```

```
Macintosh-2:Desktop $ ./a.out
Data: 1  Next: 0x100130
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Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
```

# One last thing . . .

```
void pnodeAddFront(struct node ** ppnodeAlist, int ix)
{
      struct node * pnodetmp;
      pnodetmp = (struct node *) malloc(sizeof(struct node));
      pnodetmp->next = pnodeAlist;
      pnodetmp->data = ix;
      pnodeAlist = tmp;
      printList(pnodeAlist);
}


int main()
{
    struct node * pnodeList;
    struct node * pnodeHead = NULL;
    pnodeList = pnodeMakeShortList();
    printList(pnodeList);
    pnodeAddFront(&pnodeList, 77);
    printList(pnodeList);
```

```
Macintosh-2:Desktop $ ./a.out
Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
Data: 77  Next: 0x100120
Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
Data: 1  Next: 0x100130
Data: 2  Next: 0x100140
Data: 3  Next: 0x0
```