CS61C
Instruction Representation and Functions, Part II

Lecture 6

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Dave Patterson
(http.cs.berkeley.edu/~patterson)

www-inst.eecs.berkeley.edu/~cs61c/schedule.html

Review 1/3

- MIPS assembly language instructions mapped to numbers in 3 formats

	6 bits	5 bits	5 bits	5 bits	5 bits	6 bits
R	op	rs	rt	rd	shamt	funct
I	op	rs	rt	immediate		
J	op	address				

  - Op field determines format

- Operands
  - Registers: $0 to $31 mapped onto $zero; $at; $v0, $v1, $a0.., $s0.., $t0.., $gp, $sp, $fp, $ra
  - Memory : Memory[0], Memory[4], Memory[8], , . . . , Memory[4294967292]
    - Index is the address of the word

Review 2/3

- Machine Language: what HW understands
  - Assembly Language: can extend machine language to simplify for programmer
  - Can encode instructions as numbers
- Big Idea: Stored Program Concept
  - From C to binary, and vice versa
  - Everything has an address
  - Pointer in C is HLL version of address
  - Binary SW distribution => Binary compatibility => Instruction set “lock in”

Instructions/Formats/“opcodes”, Regs

Instr.	Format	op	funct
•add	Register	0	32
•sub	Register	0	34
•slt	Register	0	42
•jr	Register	0	8
•lw	Immediate	35	
•sw	Immediate	43	
•addi	Immediate	8	
•beq	Immediate	4	
•bne	Immediate	5	
•slti	Immediate	10	
•j	Jump	2	
•jal	Jump	3	

°Name	Number
•$zero	$0
•$at	$1
•$v0,$v1	$2-$3
•$a0-$a3	$4-$7
•$t0-$t7	$8-$15
•$s0-$s7	$16-$22
•$t8-$t9	$23-$24
•$k0,$k1	$26,$27
•$gp	$28
•$sp)	$29
•$fp($t10)	$30
•$ra	$31

Overview

- Decoding Instructions from numbers
- Why MIPS?
- C Function Memory Allocation review
- Administrivia,“Cool Technology”
- 4 Versions of C/Asm. sumarray function
- Pointers and memory allocation in C
- Conclusion

Decoding example

- Binary=>Decimal=>Assembly=>C?
- Start at program at address 4,194,304 (2^{22})

```
00000000000000000001000000100000
00000000000001010100100000101010
00010001001000000000000000000101
00000000010001000001000000100000
00100000101001011111111111111111
00000000000001010100100000101010
00010101001000001111111111111101
```

- What are instruction formats of these 7 instructions?

Decoding example: Binary=>Decimal

- Binary=>Decimal=>Assembly=>C?

R	000000	00000	00000	00010	00000	100000
R	000000	00000	00101	01001	00000	101010
I	000100	01001	00000	0000000000000101		
R	000000	00010	00100	00010	00000	100000
I	001000	00101	00101	1111111111111111		
R	000000	00000	00101	01001	00000	101010
I	000101	01001	00000	1111111111111100		

R	0	0	0	2	0	32
R	0	0	5	9	0	42
I	4	9	0	5		
R	0	2	4	2	0	32
I	8	5	5	-1		
R	0	0	5	9	0	42
I	5	9	0	-4		

Decoding example: Decimal=>Assembly

- Decimal=>Assembly? (Slide 4)

R	0	0	0	2	0	32
R	0	0	5	9	0	42
I	4	9	0	5		
R	0	2	4	2	0	32
I	8	5	5	-1		
R	0	0	5	9	0	42
I	5	9	0	-4		

```
4194304 add    $2, $0, $0
4194308 slt    $9, $0, $5
4194312 beq    $9, $0, 5
4194316 add    $2, $2, $4
4194320 addi   $5, $5, -1
4194324 slt    $9, $0, $5
4194328 bne    $9, $0, -4
```

Decoding example: Symbolic Assembly

- Registers, see Slide 4

```
4194304   add     $2, $0, $0
4194308   slt     $9, $0, $5
4194312   beq     $9, $0, 5
4194316   add     $2, $2, $4
4194320   addi    $5, $5, -1
4194324   slt     $9, $0, $5
4194328   bne     $9, $0, -4
```

```
          add     $v0,$zero,$zero
          slt     $t1,$zero,$a1
          beq     $t1,$zero, Exit
Loop:     add     $v0,$v0,$a0
          addi    $a1,$a1, -1
          slt     $t1,$zero,$a1
          bne     $t1,$zero,Loop
Exit:
```

Decoding example: Assembly=>C

- Binary=>Decimal=>Assembly=>C?

MIPS

```
        add     $v0,$zero,$zero
        slt     $t1,$zero,$a1
        beq     $t1,$zero, Exit
Loop:   add     $v0,$v0,$a0
        addi    $a1,$a1, -1
        slt     $t1,$zero,$a1
        bne     $t1,$zero,Loop
Exit:
```

- Mapping product:v0, mcand:a1, mlier:a1;

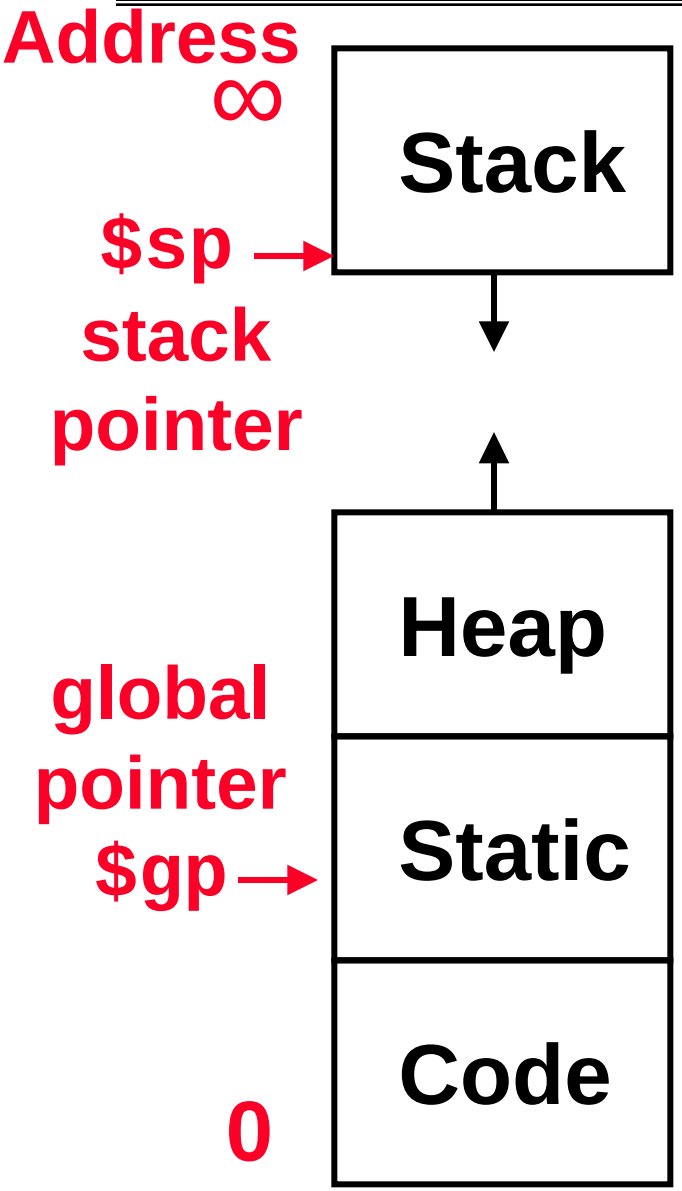
C

```
product = 0;
while (0 < mlier)  {
 product = product + mcand;
 mlier = mlier - 1;
 }
```

Why MIPS?

- Example of modern design: RISC, or Reduced Instruction Set Computer
  - Style of computer, e.g., sports car
  - RISC developed at IBM, Berkeley, Stanford
- RISCs much easier to understand v. x86
- 1998 32-bit Embedded Processors
  - 83M Motorola 680x0
  - 50M MIPS
  - 48M ARM (Acorn RISC Machine)
  - 26M Hitachi SuperH (RISC)
  - 12M x86 (5% of market)

Review: C memory allocation



Space for saved procedure information

Explicitly created space, e.g., malloc(); C pointers

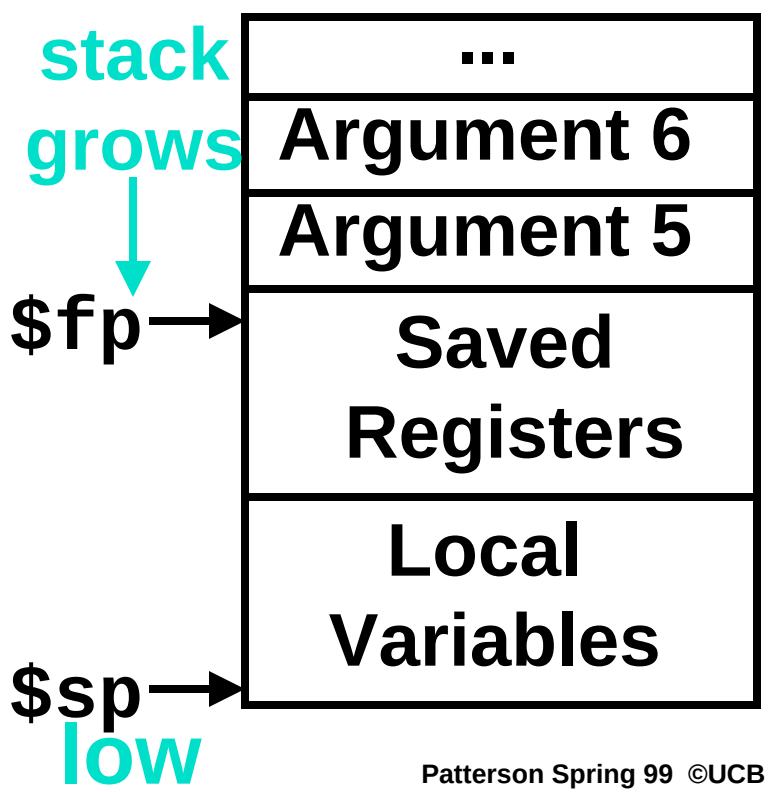
Variables declared once per program

Program

Review: Memory Allocation on Call

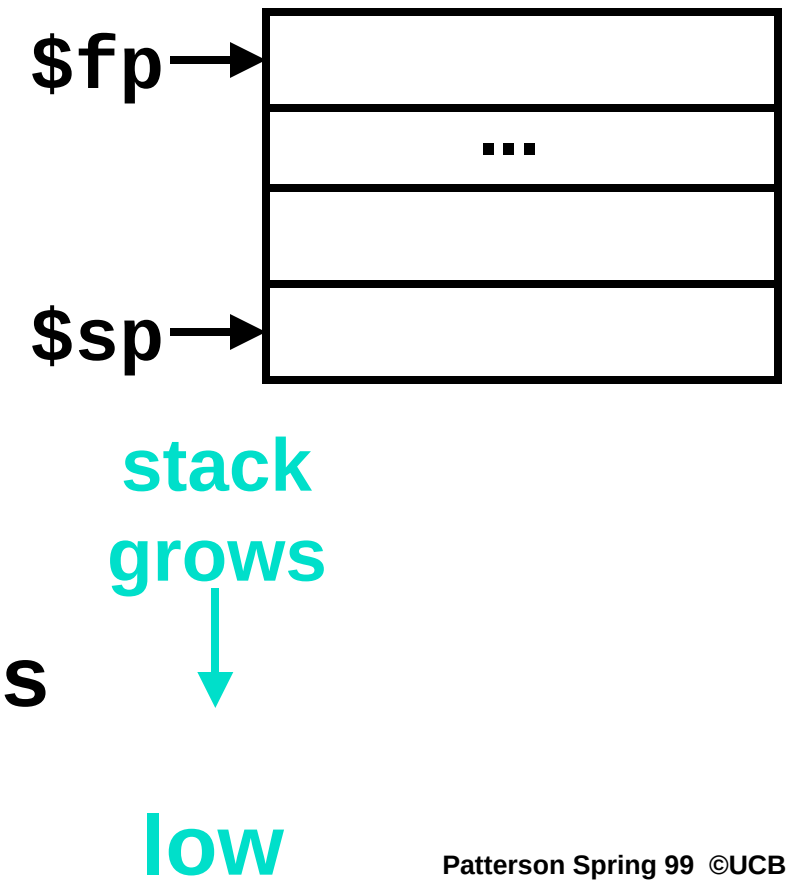
C Procedure Call Frame

- Pass arguments (4 regs)
- Save caller-saved regs
- `jal`
- space on stack ($sp-n)
- save $fp & set $fp 1st word of frame ($sp+n-4)
- Save callee-saved regs
- If may call functions, save arguments and $ra



Review: Memory Deallocation on Return

- Move return value into $v0
- Restore callee-saved regs from the stack
- If saved $ra, restore it
- Restore $fp from stack
- Pop stack ($sp+n) $sp@last word of frame
- `jr $ra`
- Restore caller-saved regs



Argument Passing Options

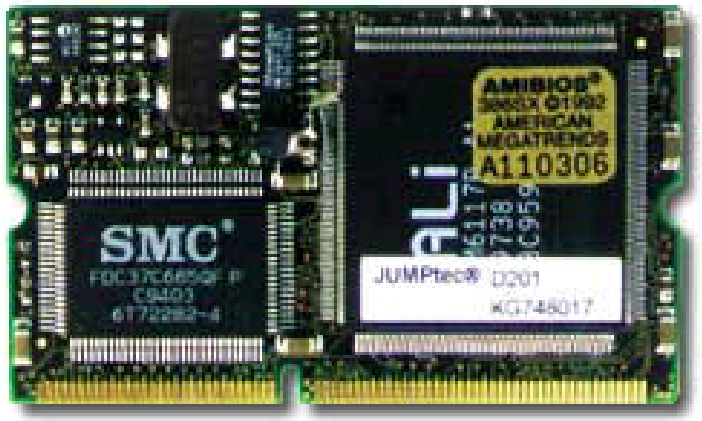
- 2 choices
  - "Call by Value": pass a copy of the item to the function/procedure
  - "Call by Reference": pass a pointer to the item to the function/procedure
- Single word variables passed by value
- Passing an array? e.g., `a[100]`
  - Pascal--call by value--copies 100 words of `a[]` onto the stack
  - C--call by reference--passes a pointer (1 word) to the array `a[]` in a register

Administrivia

- Readings: 3.7,4.1,4.2,4.3
- 3rd homework: Due Wed 2/10 7PM
  - Exercises 3.7, 3.8, 3.10
- 2nd project: MIPS Disassembler Due Wed. 2/17 7PM
- Midterm, Final: 5-8PM (3/17, 5/12)
  - Conflicts: email mds@cory

Cool Technology: DIMM-PC/486

- 486 PC smaller than a credit card



- ELAN410 66MHz (486) CPU, 16 MB of DRAM, 16 MB of flash; all standard PC interfaces, such as 2 serial ports, printer, floppy and a hard disk interface; Ethernet option, Redhat 5.2 Linix: `www.jumptec.com`
- 1.6” x 2.7” x 0.25”, 0.8 w standby, $419,

“Computers in the News”

- **“Intel Alters Plan Said To Undermine PC Users' Privacy”, 1st p., N.Y. Times 1/26/99**
- **Processor-specific IDs per chip accessed by SW and transmitted over the Internet**
  - 96-bit unique serial number: 32 CPU type+64 ID
  - **Idea: ID helps intellectual property protection, tying apps, information to a specific machine**
- **“Big Brother” inside? Boycott Intel!**
  - No anonymity? Track 1 consumer over Internet?
- **“The Intel Corporation yesterday reversed a plan to activate an identifying signature in its next generation of computer chips, bowing to protests that the technology would compromise the privacy of users.”**
  - Not removed; default now off on reboot

Arrays, Pointers, Functions in C

- 4 versions of array function that adds two arrays and puts sum in a third array (`sumarray`)
  - Third array is passed to function
  - Using a local array (on stack) for result and passing a pointer to it
  - Third array is allocated on heap
  - Third array is declared static
- Purpose of example is to show interaction of C statements, pointers, and memory allocation

Calling `sumarray`, Version 1

```
int x[100], y[100], z[100];

sumarray(x, y, z);
```

- C calling convention means above the same as

```
sumarray(&x[0], &y[0], &z[0]);
```

- Really passing pointers to arrays

```
addi $a0,$gp,0   # x[0] starts at $gp
addi $a1,$gp,400 # y[0] above x[100]
addi $a2,$gp,800 # z[0] above y[100]
jal  sumarray
```

Version 1: Optimized Compiled Code

```
void sumarray(int a[],int b[],int c[]) {
  int i;

  for(i=0;i<100;i=i+1)
     c[i] = a[i] + b[i];

}
```

```
      addi $t0,$a0,400 # beyond end of a[]
Loop: beq  $a0,$t0,Exit
      lw   $t1, 0($a0) # $t1=a[i]
      lw   $t2, 0($a1) # $t2=b[i]
      add  $t1,$t1,$t2 # $t1=a[i] + b[i]
      sw   $t1, 0($a2) # c[i]=a[i] + b[i]
      addi $a0,$a0,4   # $a0++
      addi $a1,$a1,4   # $a1++
      addi $a2,$a2,4   # $a2++
      j    Loop
Exit: jr   $ra
```

Version 1: Before optimizing compilers

```
void sumarray(int a[],int b[],int c[]) {
  int *p = &a[100];

  while (a != p) {
     *c = *a + *b; a++; b++; c++;}

}
```

```
      addi $t0,$a0,400 # beyond end of a[]
Loop: beq  $a0,$t0,Exit
      lw   $t1, 0($a0) # $t1=a[i]
      lw   $t2, 0($a1) # $t2=b[i]
      add  $t1,$t1,$t2 # $t1=a[i] + b[i]
      sw   $t1, 0($a2) # c[i]=a[i] + b[i]
      addi $a0,$a0,4   # $a0++
      addi $a1,$a1,4   # $a1++
      addi $a2,$a2,4   # $a2++
      j    Loop
Exit: jr   $ra
```

Version 2 to Fix Weakness of Version 1

- Would like recursion to work

```
int sumarray(int a[],int b[]);
 /* adds 2 arrays and returns sum */

sumarray(x, sumarray(y,z));
```

- Cannot do this with Version 1 style solution: what about this

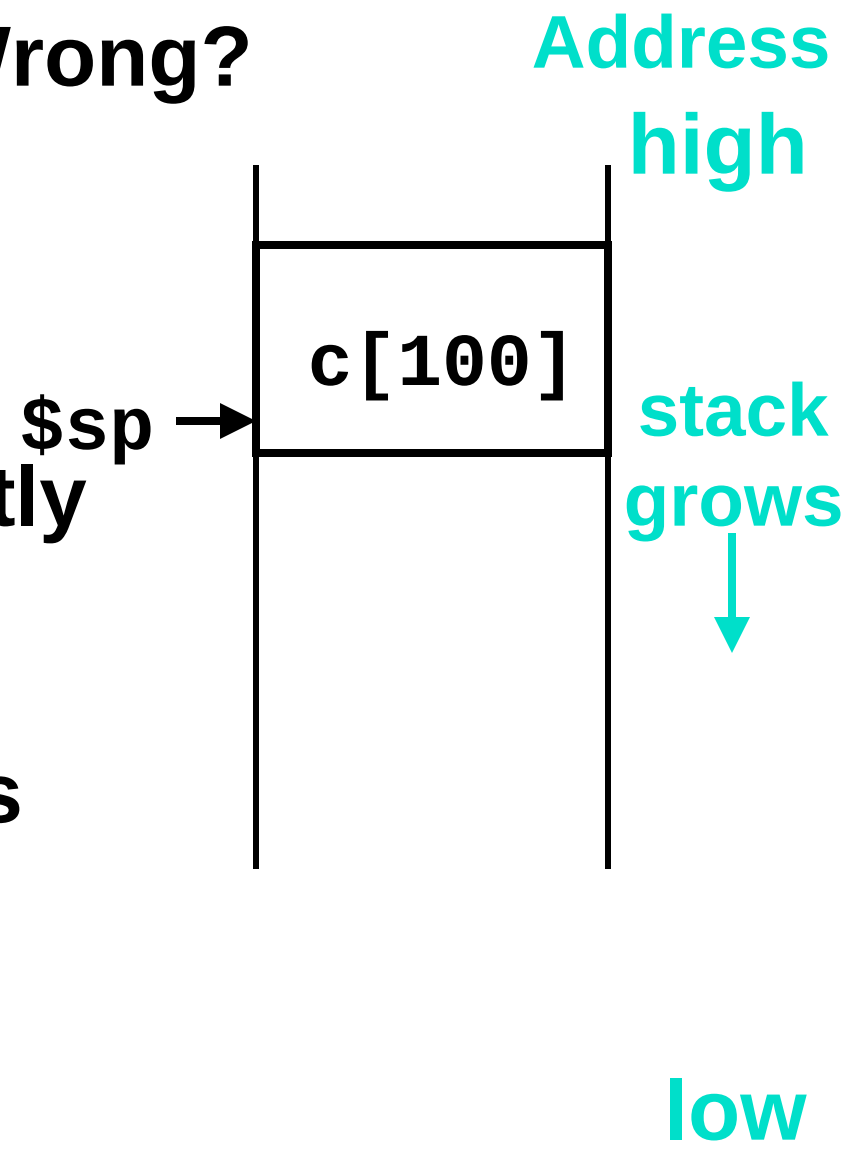
```
int * sumarray(int a[],int b[]) {
    int i, c[100];
    for(i=0;i<100;i=i+1)
          c[i] = a[i] + b[i];
    return c;
}
```

Version 2: Revised Compiled Code

```
 for(i=0;i<100;i=i+1)
    c[i] = a[i] + b[i];
 return c;}
      addi $t0,$a0,400 # beyond end of a[]
      addi $sp,$sp,-400# space for c
      addi $t3,$sp,0   # ptr for c
      addi $v0,$t3,0   # $v0 = &c[0]
Loop: beq  $a0,$t0,Exit
      lw   $t1, 0($a0) # $t1=a[i]
      lw   $t2, 0($a1) # $t2=b[i]
      add  $t1,$t1,$t2 # $t1=a[i] + b[i]
      sw   $t1, 0($t3) # c[i]=a[i] + b[i]
      addi $a0,$a0,4   # $a0++
      addi $a1,$a1,4   # $a1++
      addi $t3,$t3,4   # $t3++
      j    Loop
Exit: addi $sp,$sp, 400# pop stack
      jr   $ra
```

Weakness of Version 2

- Legal Syntax; What's Wrong?
- Will work until call another function that uses stack
- Won't be reused instantly (e.g, add a `printf`)
- Stack allocated + unrestricted pointer is problem



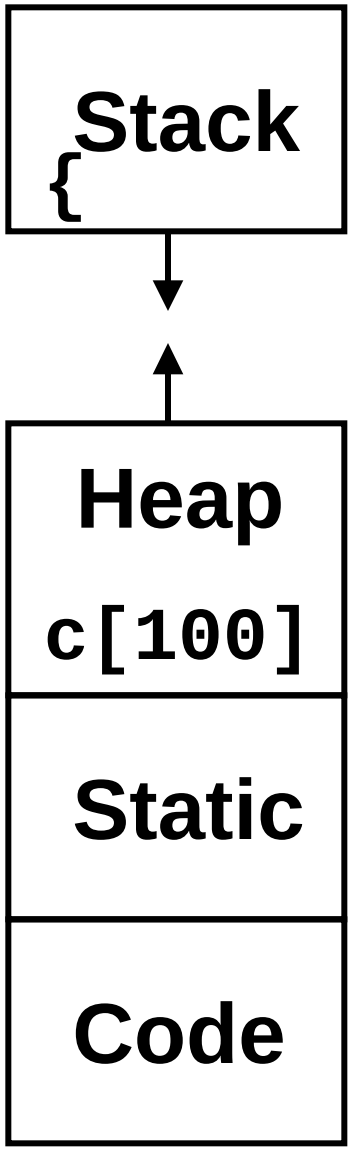
Version 3 to Fix Weakness of Version 2

- Solution: allocate c[] on heap

```
int * sumarray(int a[],int b[]) {
    int i;
    int *c;

    c = (int *) malloc(100);

    for(i=0;i<100;i=i+1)
          c[i] = a[i] + b[i];
    return c;
}
```



- Not reused unless freed
  - Can lead to memory leaks
  - Java, Scheme have garbage collectors to reclaim free space

Version 3: Revised Compiled Code

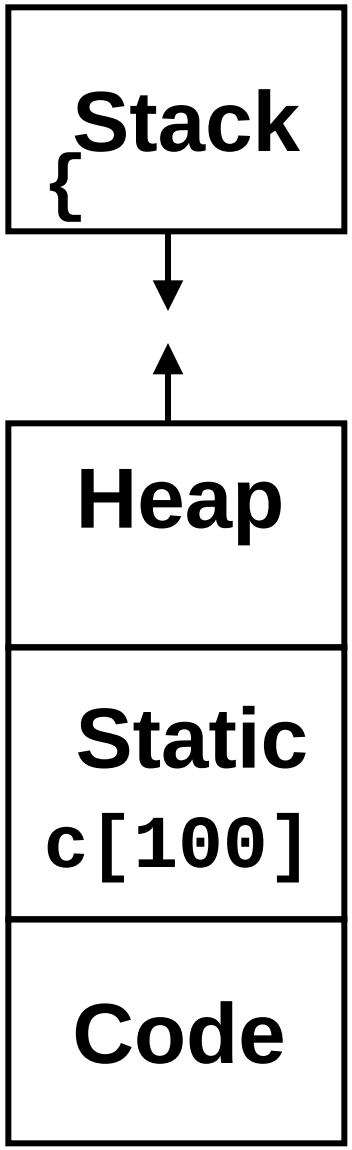
```
        addi $t0,$a0,400 # beyond end of a[]
        addi $sp,$sp,-12 # space for regs
        sw   $ra, 0($sp) # save $ra
        sw   $a0, 4($sp) # save 1st arg.
        sw   $a1, 8($sp) # save 2nd arg.
        addi $a0,$zero,400 #
        jal  malloc
        addi $t3,$v0,0   # ptr for c
        lw   $a0, 4($sp) # restore 1st arg.
        lw   $a1, 8($sp) # restore 2nd arg.
Loop:   beq  $a0,$t0,Exit
        ... (loop as before on prior slide )
        j    Loop
Exit:   lw   $ra, 0($sp) # restore $ra
        addi $sp,$sp, 12 # pop stack
        jr   $ra
```

Version 4 : Alternative to Version 3

- Static declaration

```
int * sumarray(int a[],int b[]) {
    int i;
    static int c[100];

    for(i=0;i<100;i=i+1)
          c[i] = a[i] + b[i];
    return c;
}
```



- Compiler allocates once for function, space is reused
  - Will be changed next time `sumarray` invoked
  - Why describe? used in C libraries

What about Structures?

- Scalars passed by value
- Arrays passed by reference (pointers)
- Structures by value too
- Can think of C passing everything by value, just that arrays are simply a notation for pointers and the pointer is passed by value

"And in Conclusion …" 1/2

- MIPS assembly language instructions mapped to numbers in 3 formats

	6 bits	5 bits	5 bits	5 bits	5 bits	6 bits
R	op	rs	rt	rd	shamt	funct
I	op	rs	rt	immediate		
J	op	address				

  - Op field determines format

- Binary => Decimal => Assembly => Symbolic Assembly => C
  - Reverse Engineering or Disassembly
  - Its hard to do, therefore people like shipping binary machine language more than assembly or C

"And in Conclusion …" 2/2

- Programming language model of memory allocation and pointers
  - Allocate in stack vs. heap vs. global areas
  - Arguments passed
    call by value vs. call by reference
  - Pointer in C is HLL version of machine address
- Next : character, strings, other numbers