Calling Conventions

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CS 3410, Spring 2011

Computer Science

Cornell University

See P&H 2.8 and 2.12

Announcements

PA1 due *this* Friday

Work in pairs

Use your resources

- FAQ, class notes, book, Sections, office hours, newsgroup, CSUGLab, etc

PA2 will be available this Friday

- PA2 builds from PA1
- Work with same partner
- Due right before spring break

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Announcements

Prelims1: next Thursday, March 10th in class

- We will start at 1:25pm sharp, so come early
- Closed Book
  - Cannot use electronic device or outside material
- Practice prelims are online in CMS
- Material covered
  - Appendix C (logic, gates, FSMs, memory, ALUs)
  - Chapter 4 (pipelined [and non-pipeline] MIPS processor with hazards)
  - Chapters 2 and Appendix B (RISC/CISC, MIPS, and calling conventions)
  - Chapter 1 (Performance)
  - HW1, HW2, PA1, PA2

Goals for Today

Calling Conventions

- Anatomy of an executing program
- Register assignment conventions,
- Function arguments, return values
- Stack frame, Call stack, Stack growth
- Variable arguments

Next time

- More on stack frames
- globals vs local accessible data
- callee vs callrer saved registers

Example program

calc.c

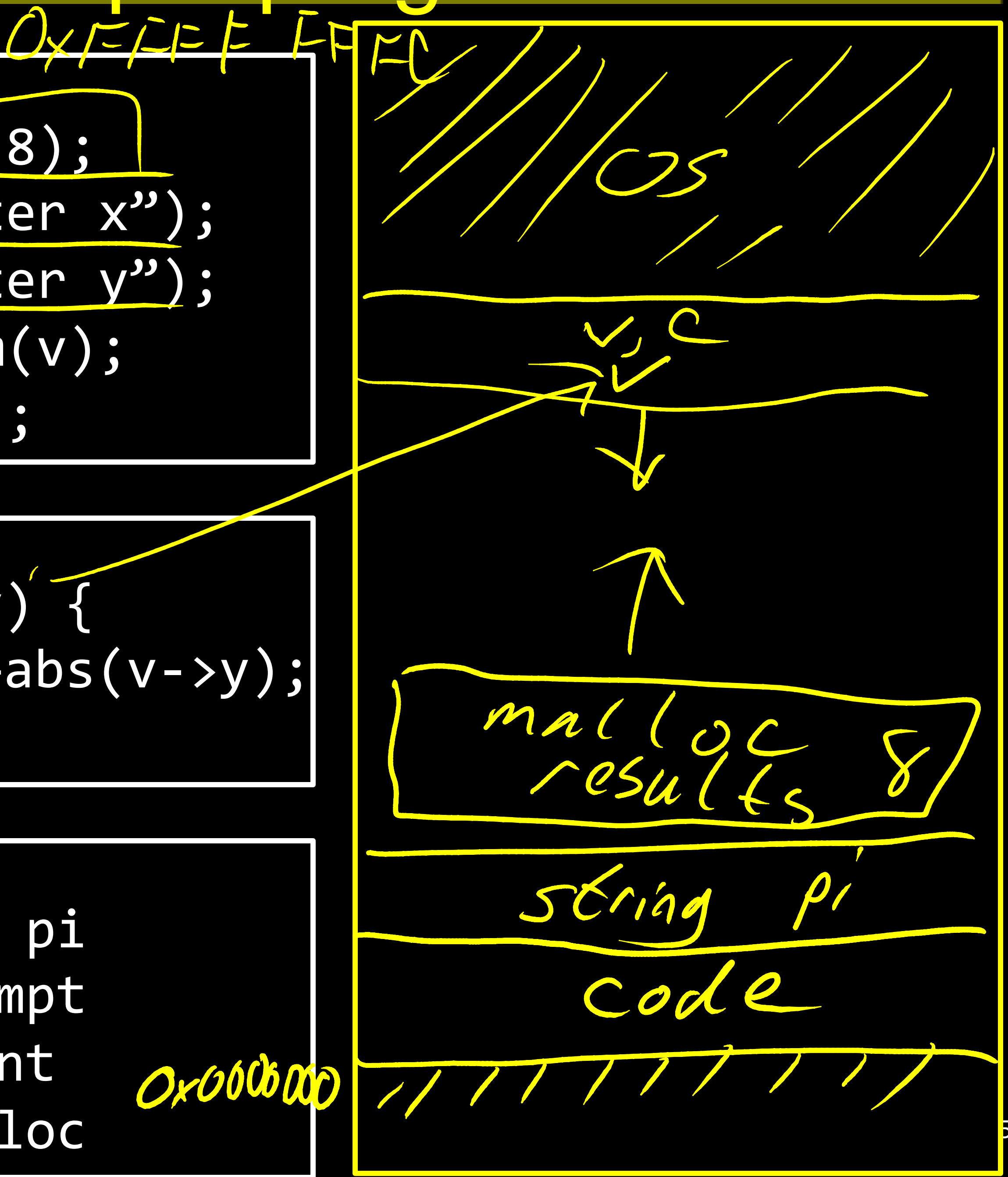
```
vector v = malloc(8);
v->x = prompt(“enter x”);
v->y = prompt(“enter y”);
int c = pi + tnorm(v);
print(“result”, c);
```

math.c

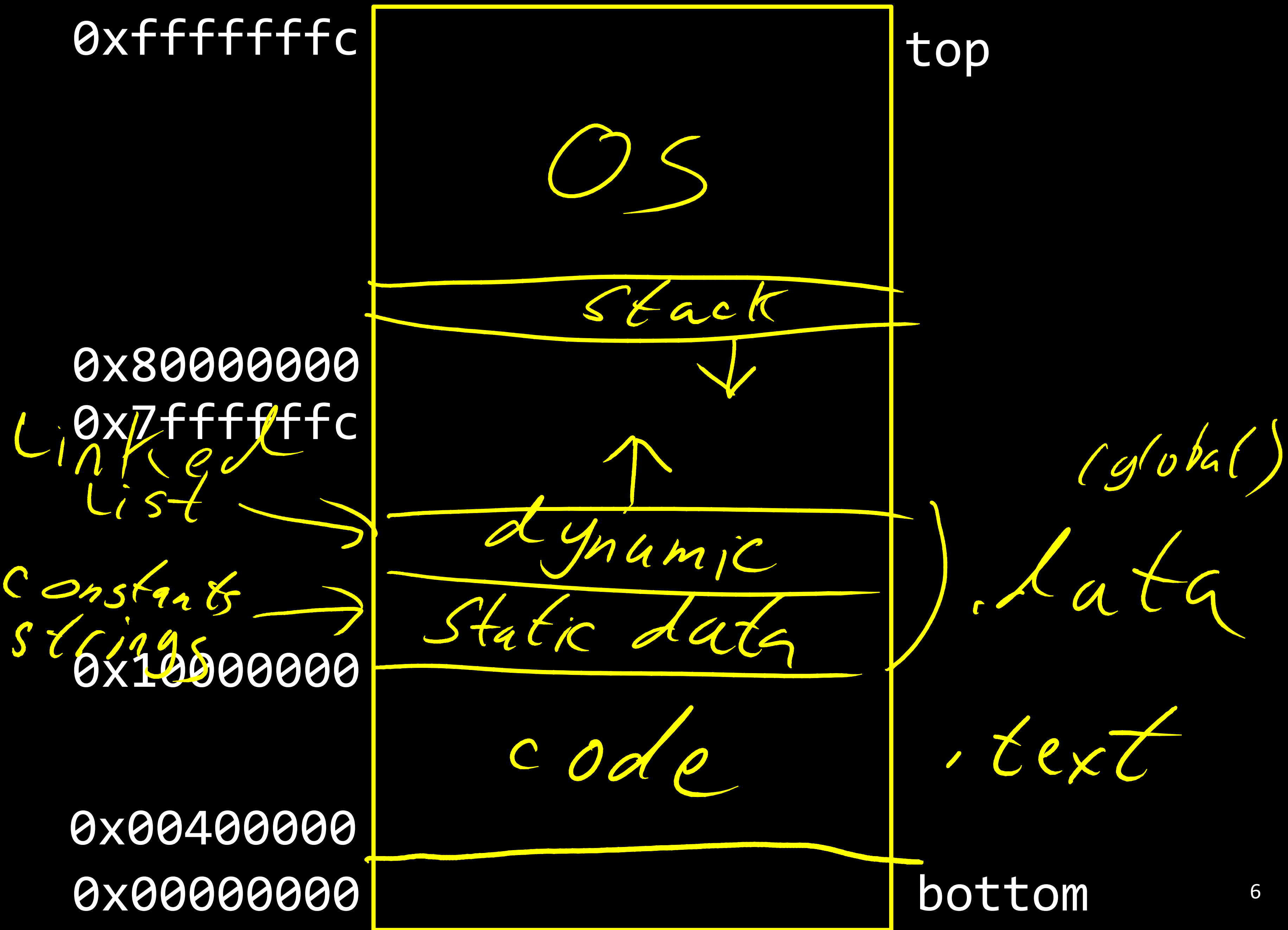
```
int tnorm(vector v) {
 return abs(v->x)+abs(v->y);
}
```

lib3410.o

```
  global variable: pi
  entry point: prompt
  entry point: print
  entry point: malloc
```



Anatomy of an executing program



0xfffffffc

top

0x80000000

0x7ffffffc

0x10000000

0x00400000

0x00000000

bottom

math.s

where to put args
ret values

math.c

```
int abs(x) {        r3
  return x < 0 ? -x : x;
}
int tnorm(vector v) {
 return abs(v->x)+abs(v->y);
}
```

abs:

# arg in r3, return address in r31

# leaves result in r3

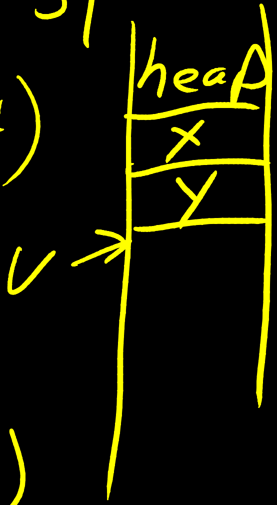
```
      BLZ  r3, neg
      J    r31
neg:  sub  r3, r0, r3
      J    r31
```

tnorm:

# arg in r4, return address in r31

# leaves result in r4

```
Move r30, r31
lw   r3, 0(r4)
JAL  abs
Move r6, r3
lw   r3 4(r4)
JAL  abs            $ra=PC+4
ADD  r4, r6, r3
JR   r30
```



calc.s

calc.c

```
vector v = malloc(8);
v->x = prompt("enter x");
v->y = prompt("enter y");
int c = pi + tnorm(v);
print("result", c);
```

```
.data
str1: .asciiz "enter x"
str2: .asciiz "enter y"
str3: .asciiz "result"
.text
  .extern prompt
  .extern print
  .extern malloc
  .extern tnorm
  .global dostuff
```

```
dostuff:
  # no args, no return value, return addr in r31
  MOVE r30, r31
  LI r3, 8         # call malloc: arg in r3, ret in r3
  JAL malloc
  MOVE r6, r3 # r6 now holds v
  LA r3, str1      # call prompt: arg in r3, ret in r3
  JAL prompt
  SW r3, 0(r6)  ✓ # store x at v.x
  LA r3, str2      # call prompt: arg in r3, ret in r3
  JAL prompt
  SW r3, 4(r6)  ✓ # store y at v+4
  MOVE r4, r6 # call tnorm: arg in r4, ret in r4
  JAL tnorm     ✓ r4 = abs(x) + abs(y)
  LA r5, pi
  LW r5, 0(r5)
  ADD r5, r4, r5
  LA r3, str3      # call print: args in r3 and r4
  MOVE r4, r5
  JAL print
  JR r30
```

PROBLEM clobbers r3, r30
r6

Calling Conventions

Calling Conventions

- where to put function arguments
- where to put return value
- who saves and restores registers, and how
- stack discipline

Why?

- Enable code re-use (e.g. functions, libraries)
- Reduce chance for mistakes

Warning: There is no one true MIPS calling convention.
lecture != book != gcc != spim != web

Example

```
void main() {
  int x = ask(“x?”);
  int y = ask(“y?”);
  test(x, y);
}

void test(int x, int y) {
  int d = sqrt(x*x + y*y);
  if (d == 1)
     print(“unit”);
  return d;
}
```

Ⓐ main calls

① ask

② test

Ⓑ test calls

① sqrt

② print

MIPS Register Conventions

r0	$zero	zero
r1	$at	assembler temp
r2	$v0	function return values
r3	$v1	
r4	$a0	function arguments
r5	$a1	
r6	$a2	
r7	$a3	
r8		
r9		
r10		
r11		
r12		
r13		
r14		
r15		

r16		
r17		
r18		
r19		
r20		
r21		
r22		
r23		
r24		
r25		
r26	$k0	reserved for OS kernel
r27	$k1	
r28		
r29		
r30		
r31	$ra	return address

Pseudo inst

BLZ = SLT $at,..,
BNE $at

Example: Invoke

```
void main() {
   int x = ask("x?");
   int y = ask("y?");
   test(x, y);
}
```

"Call stack" assures
r16 ← $ra
do not change

```
main:                                   data
                                        strX "x"
LA $a0, strX                            strY "y"
JAL ask # result in $v0
Move $r16, $v0
LA $a0, strY
JAL ask # result in $v0
Move $r17, $v0
Move $a0, r16 # x
Move $a1, r17 # y
JAL test
JR $ra
```

Call Stack

Call stack

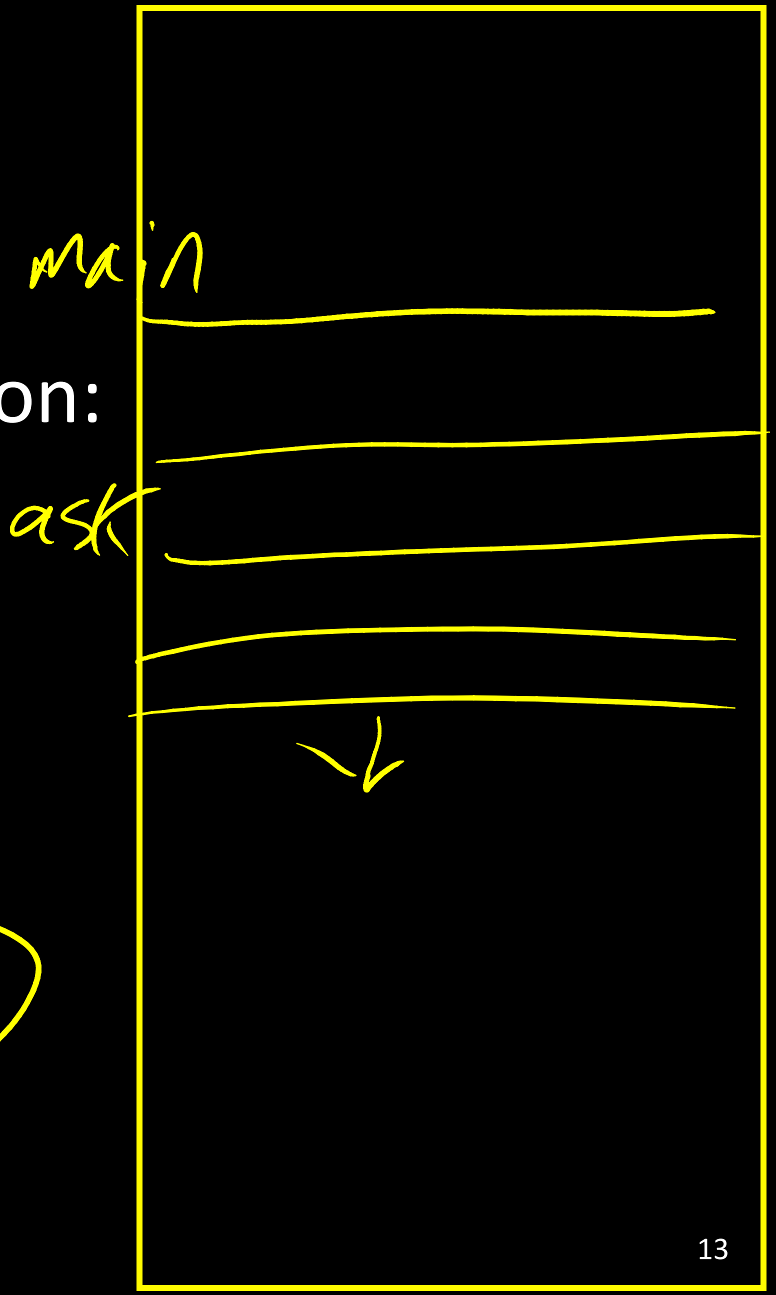
- contains *activation records* (aka *stack frames*)

One for each function invocation:

- saved return address
- local variables
- … and more

Simplification:

- frame size & layout decided at compile time for each function



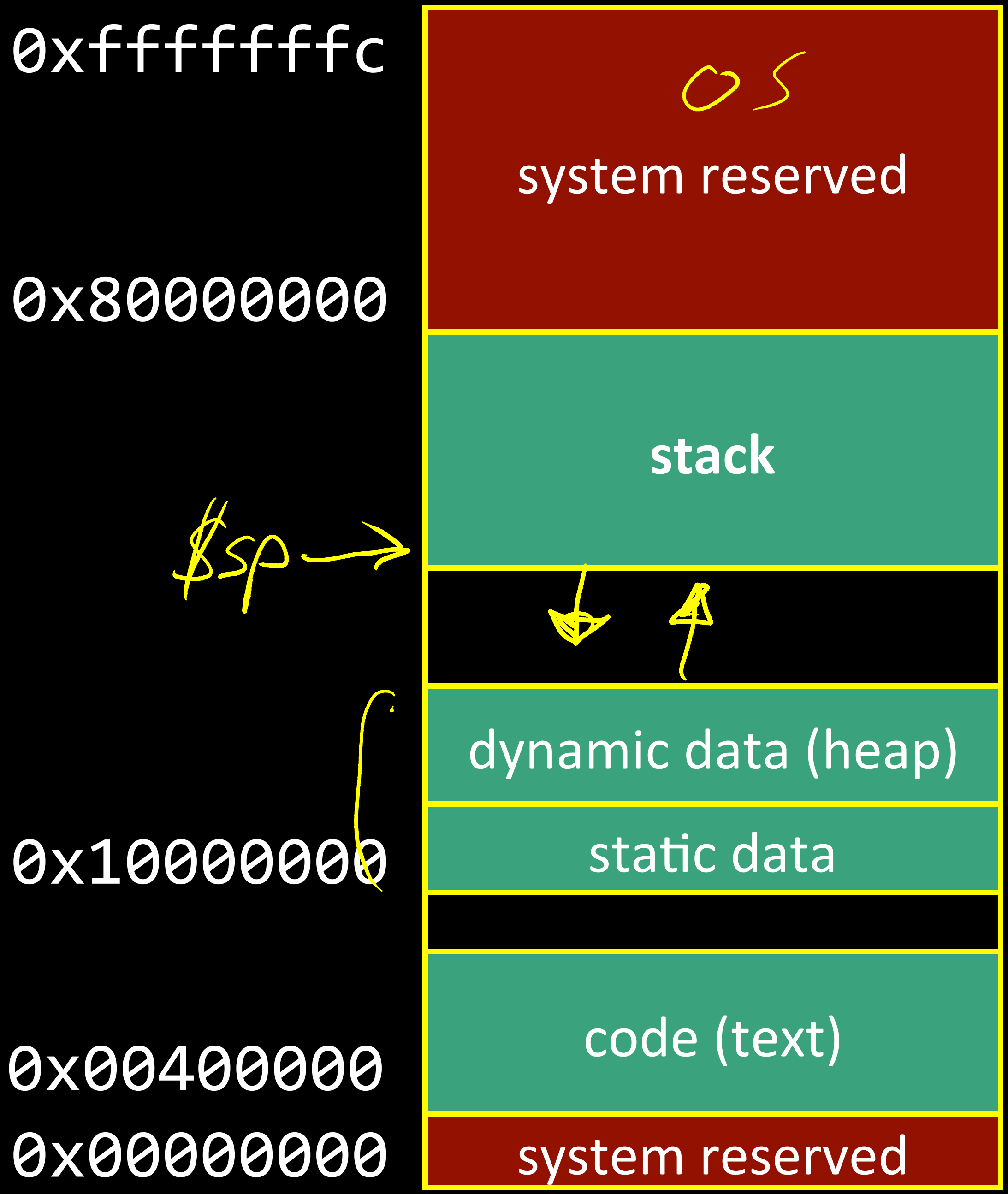
Stack Growth

Convention:

- r29 is $sp (bottom elt of call stack)

Stack grows **down**

Heap grows **up**



0xfffffffc

OS

system reserved

0x80000000

stack

$sp →

dynamic data (heap)

0x10000000

static data

0x00400000

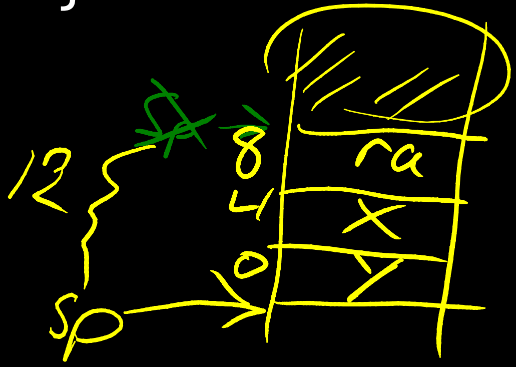
code (text)

0x00000000

system reserved

Example: Stack frame push / pop

```
void main() {
   int x = ask("x?");
   int y = ask("y?");
   test(x, y);
}
```



```
main:
   # allocate frame
   ADDUI $sp, $sp, -12 # $ra, x, y
   # save return address in frame
   SW  $ra, 8($sp)

   sw $v0, 4($sp)

   sw $v0, 0($sp)

   # restore return address
   LW $ra, 8($sp)
   # deallocate frame
   ADDUI $sp, $sp, 12
   JR $ra
```

callee push stack frame

pop stack frame

Recap

Conventions so far:

- args passed in $a0, $a1, $a2, $a3
- return value (if any) in $v0, $v1
- stack frame at $sp
  - contains $ra (clobbered on JAL to sub-functions)
  - contains local vars (possibly clobbered by sub-functions)

Q: What about real argument lists?

Arguments & Return Values

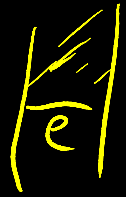
int min(int a, int b); $a0, a1

int paint(char c, short d, struct point p); $a0, $a1

int treesort(struct Tree *root, int[] A); $a2, $3

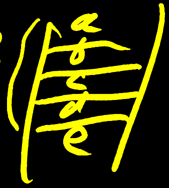
struct Tree *createTree(); 32bits $a0, $a1

int max(int a, int b, int c, int d, int e);



Conventions: a, b, c, d in regs

- align everything to multiples of 4 bytes e on stack
- first 4 words in $a0...$a3, "spill" rest to stack a0-a3



Argument Spilling

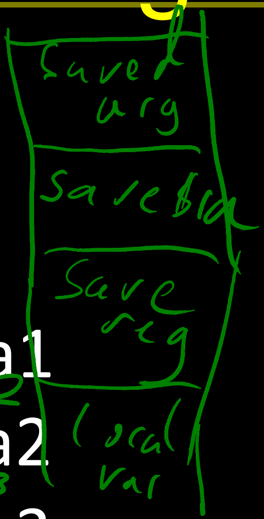
invoke sum(0, 1, 2, 3, 4, 5);

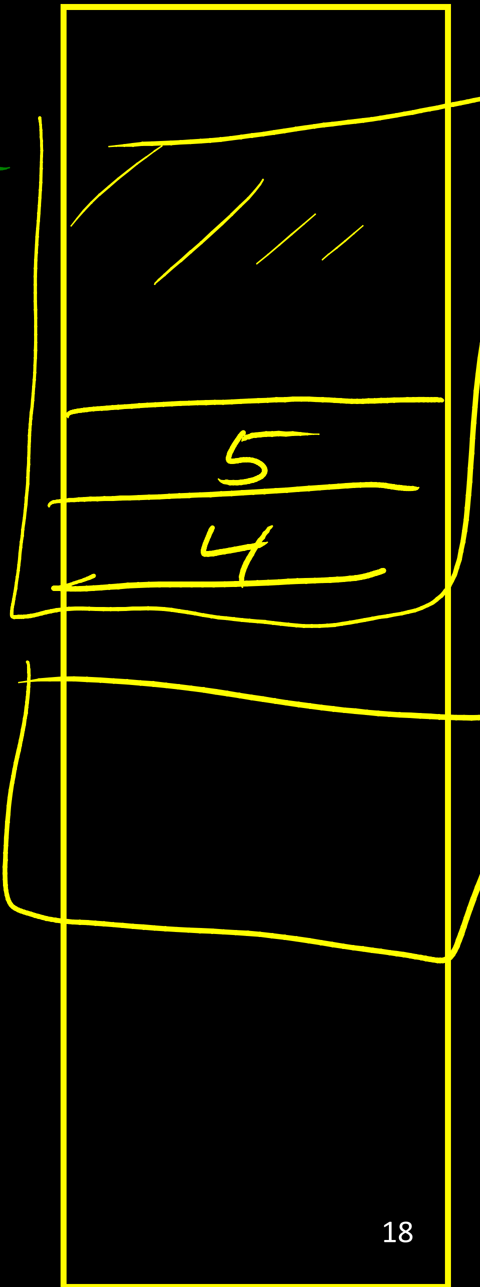
main:

```
...
LI $a0, 0
LI $a1, 1
LI $a2, 2
LI $a3, 3
ADDI $sp, $sp, -8
LI r8, 4
SW r8,   0($sp)
LI r8, 5
SW r8,   4($sp)
JAL sum
ADDI $sp, $sp, 8
```

sum:

```
...            1 = 0+1
ADD $v0, $a0, $a1
               3 = 1+2
ADD $v0, $v0, $a2
               6 = 3+3
ADD $v0, $v0, $a3
LW $v1, 0($sp)
               10 = 6+4
ADD $v0, $v0, $v1
               5
LW $v1, 4($sp)
               15 = 10+5
ADD $v0, $v0, $v1
...
JR $ra
```





Argument Spilling

printf(fmt, …)

```
main:
…
LI $a0, str0
LI $a1, 1
LI $a2, 2
LI $a3, 3
# 2 slots on stack
LI r8, 4
SW r8,   0($sp)
LI r8, 5
SW r8,   4($sp)
JAL sum
```

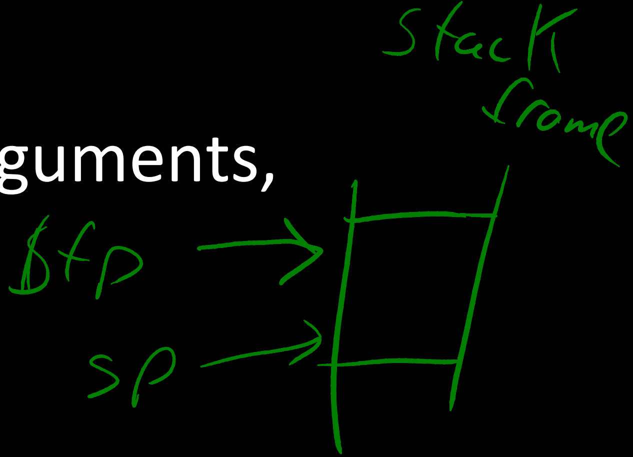
```
printf:
…
if (argno == 0)
        use $a0
else if (argno == 1)
        use $a1
else if (argno == 2)
        use $a2
else if (argno == 3)
        use $a3
else
        use $sp+(4*argno)
…
```

VarArgs

Variable Length Arguments

Initially confusing but ultimately simpler approach:

- Pass the first four arguments in registers, as usual
- Pass the rest on the stack (in order)
- Reserve space on the stack for all arguments, including the first four



Simplifies varargs functions

- Store a0-a3 in the slots allocated in parent’s frame
- Refer to all arguments through the stack

Recap

Conventions so far:

- first four arg words passed in $a0, $a1, $a2, $a3
- remaining arg words passed on the stack
- return value (if any) in $v0, $v1
- stack frame at $sp
  - contains $ra (clobbered on JAL to sub-functions)
  - contains local vars (possibly clobbered by sub-functions)
  - contains extra arguments to sub-functions
  - contains **space** for first 4 arguments to sub-functions