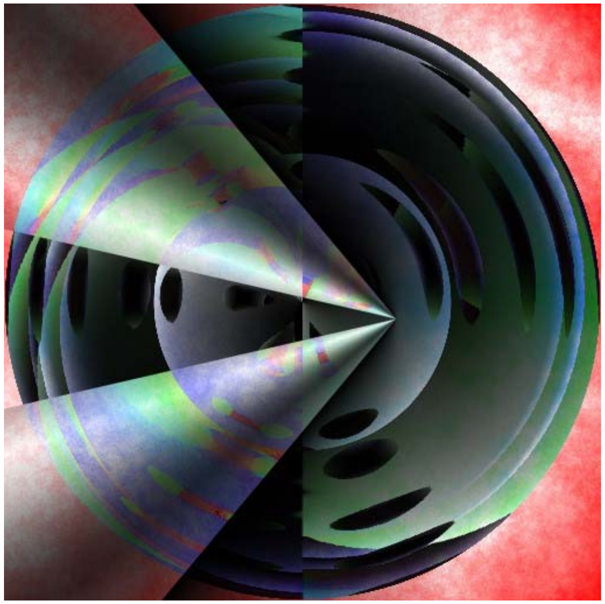
inst.eecs.berkeley.edu/~cs61c/su06

CS61C : Machine Structures

Lecture #6: Intro to MIPS

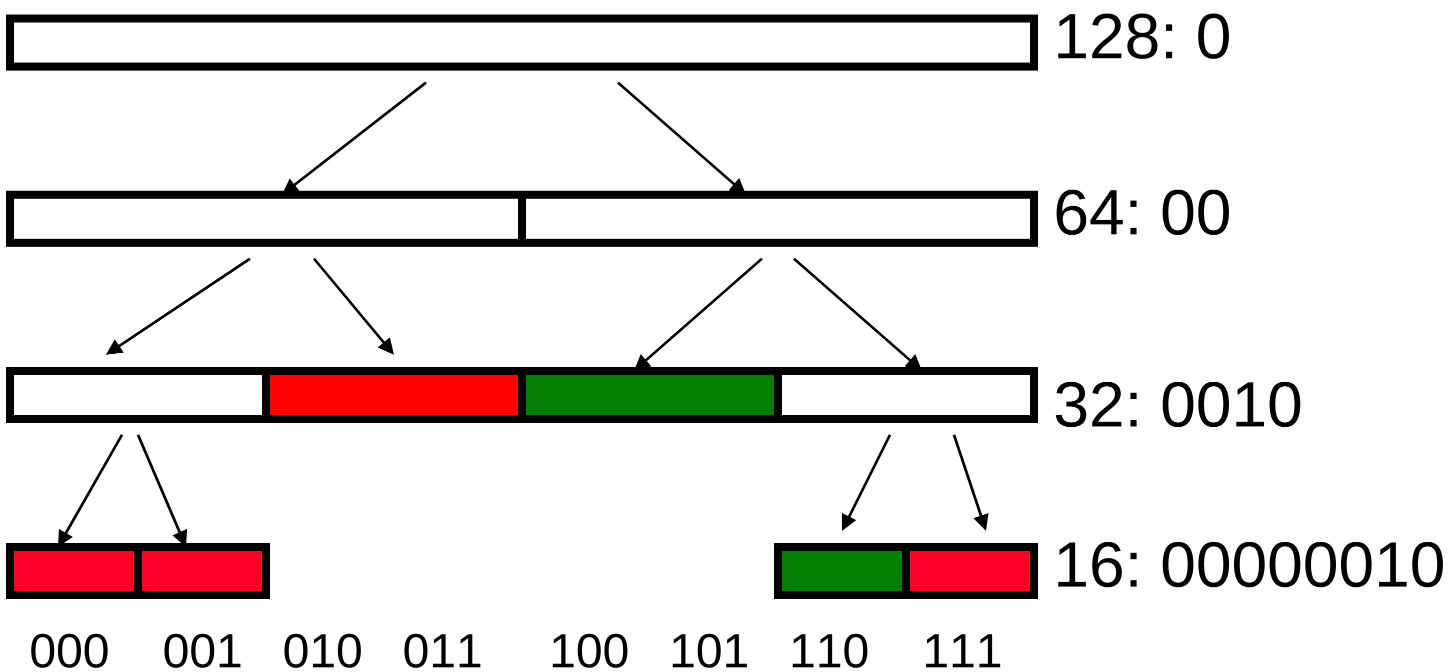


2006-07-06

Andy Carle

Buddy System Review

- Legend: FREE ALLOCATED SPLIT



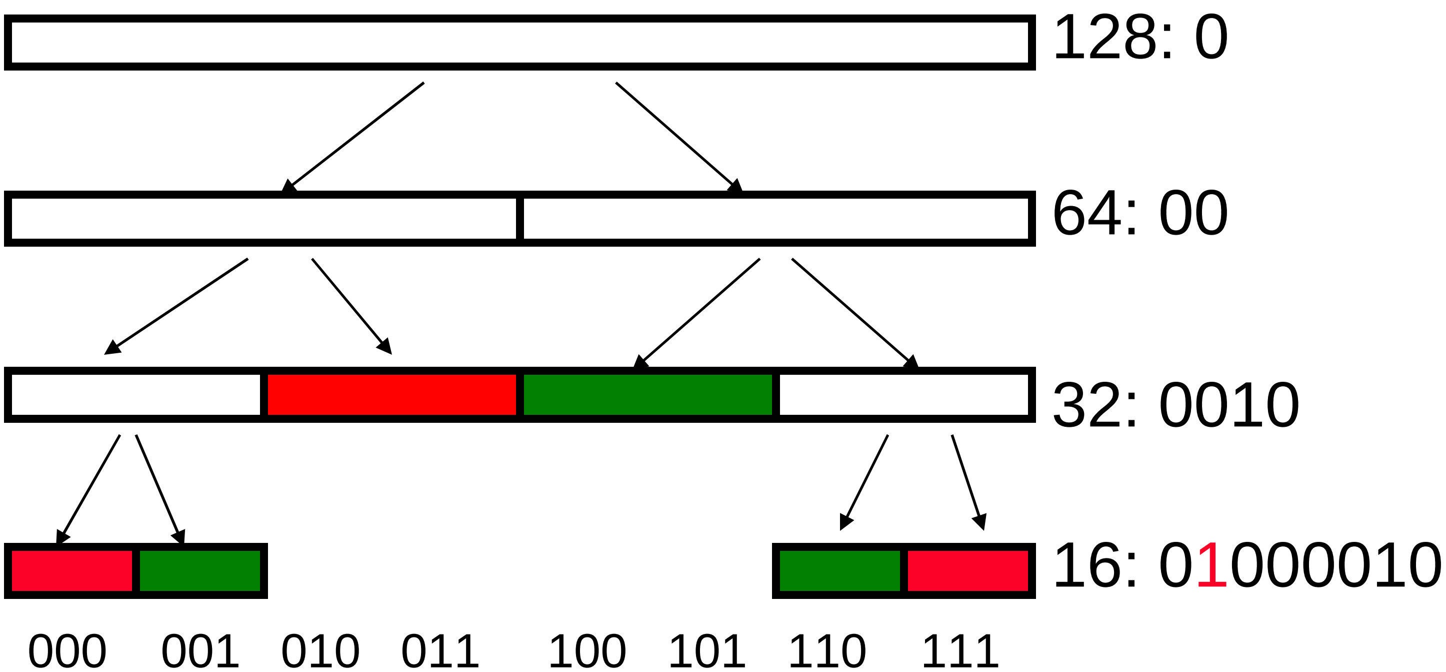
Initial State ➔ Free(001) ➔ Free(000) ➔ Free(111) ➔ Malloc(16)

1

Kudos to Kurt Meinz for these fine slides

Buddy System

- **Legend: FREE ALLOCATED SPLIT**



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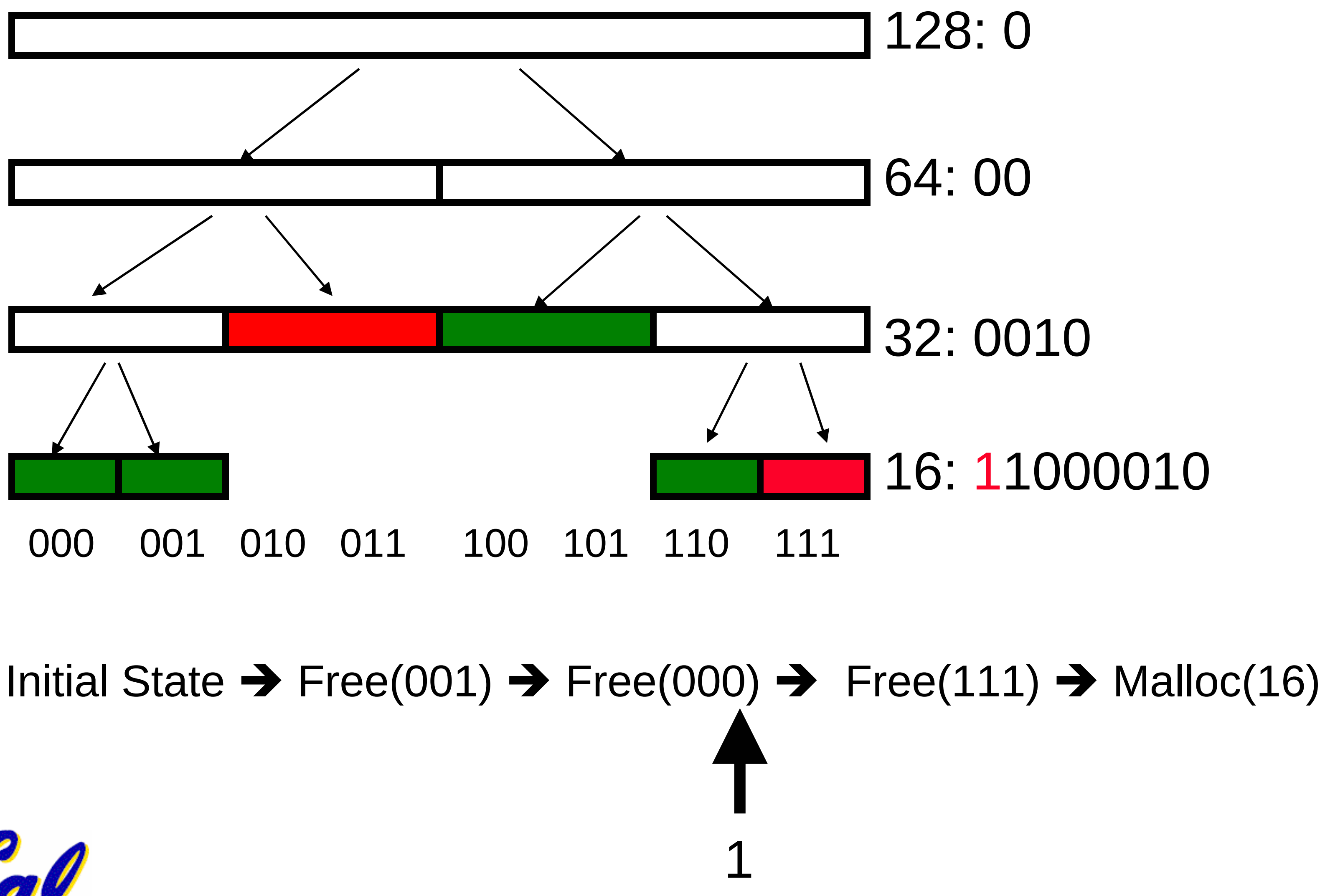
1

Buddy System

- **Legend:** **FREE** **ALLOCATED** **SPLIT**



Buddy System

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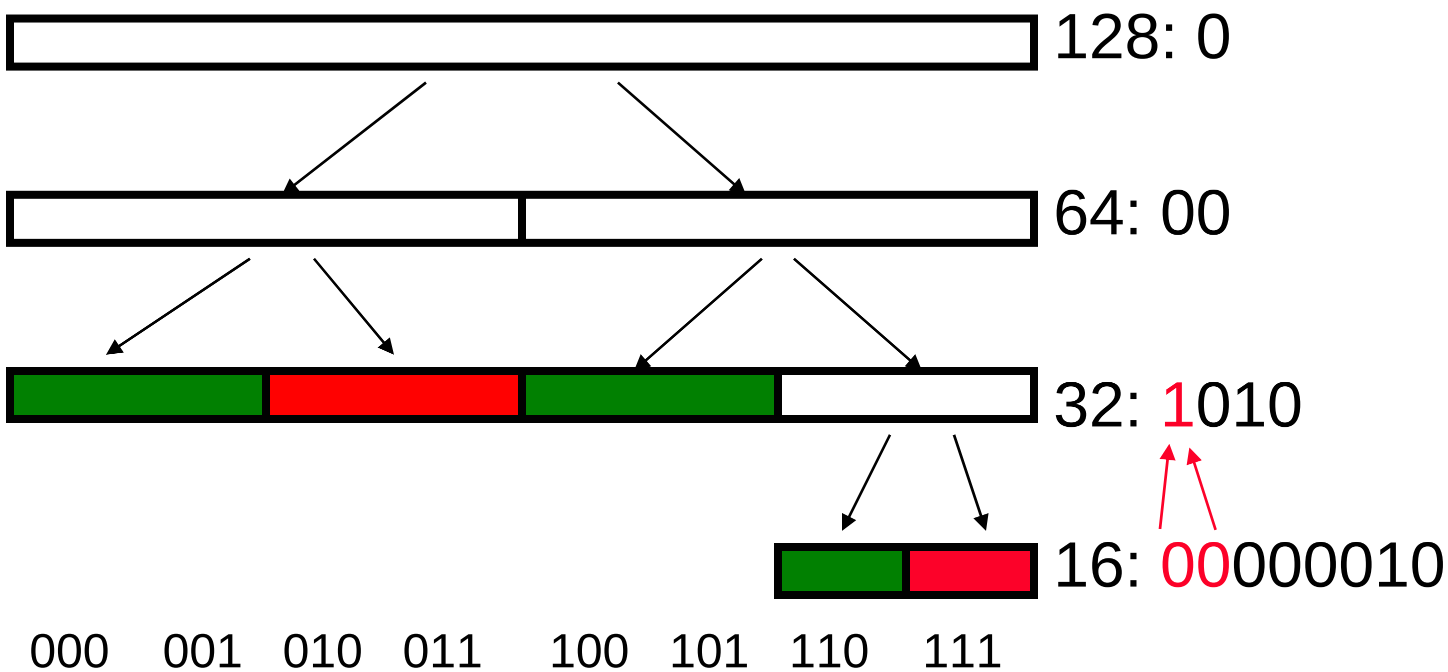

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↑

2

Buddy System

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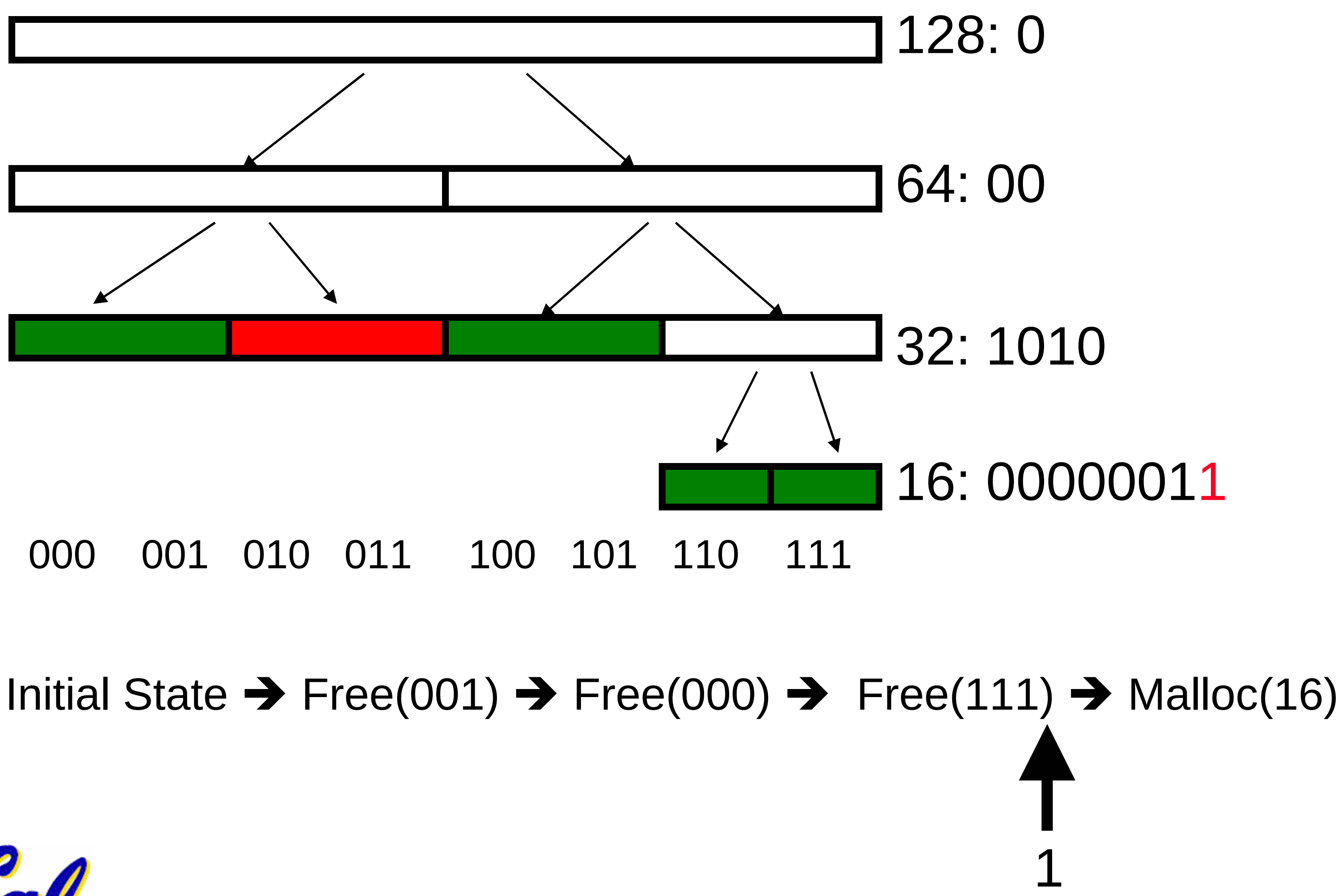

Buddy System

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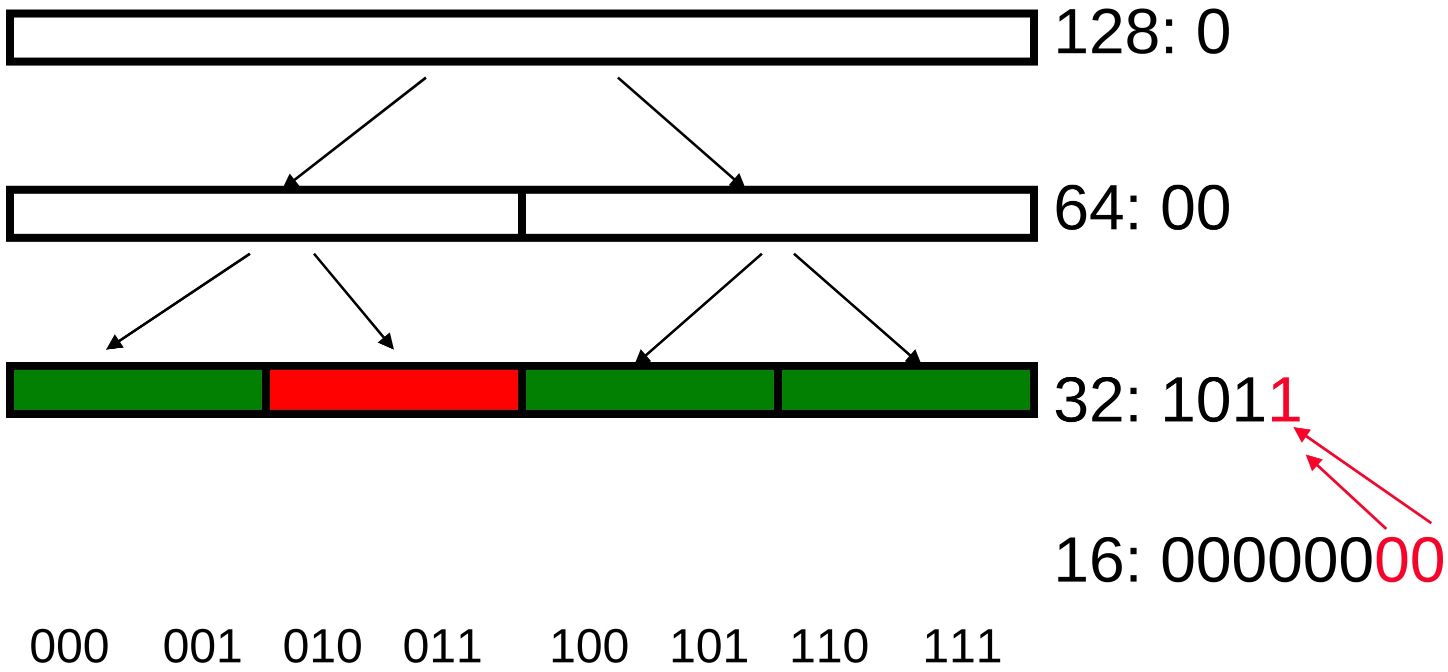

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2

Buddy System

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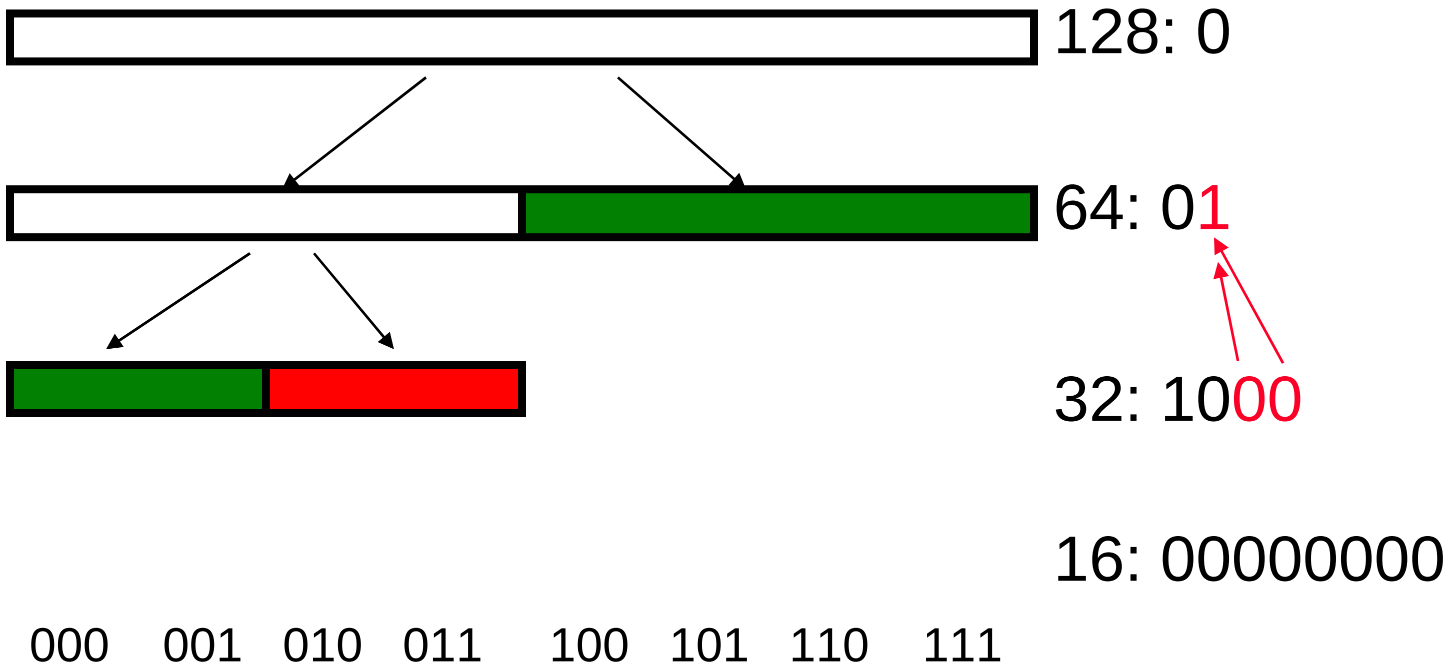

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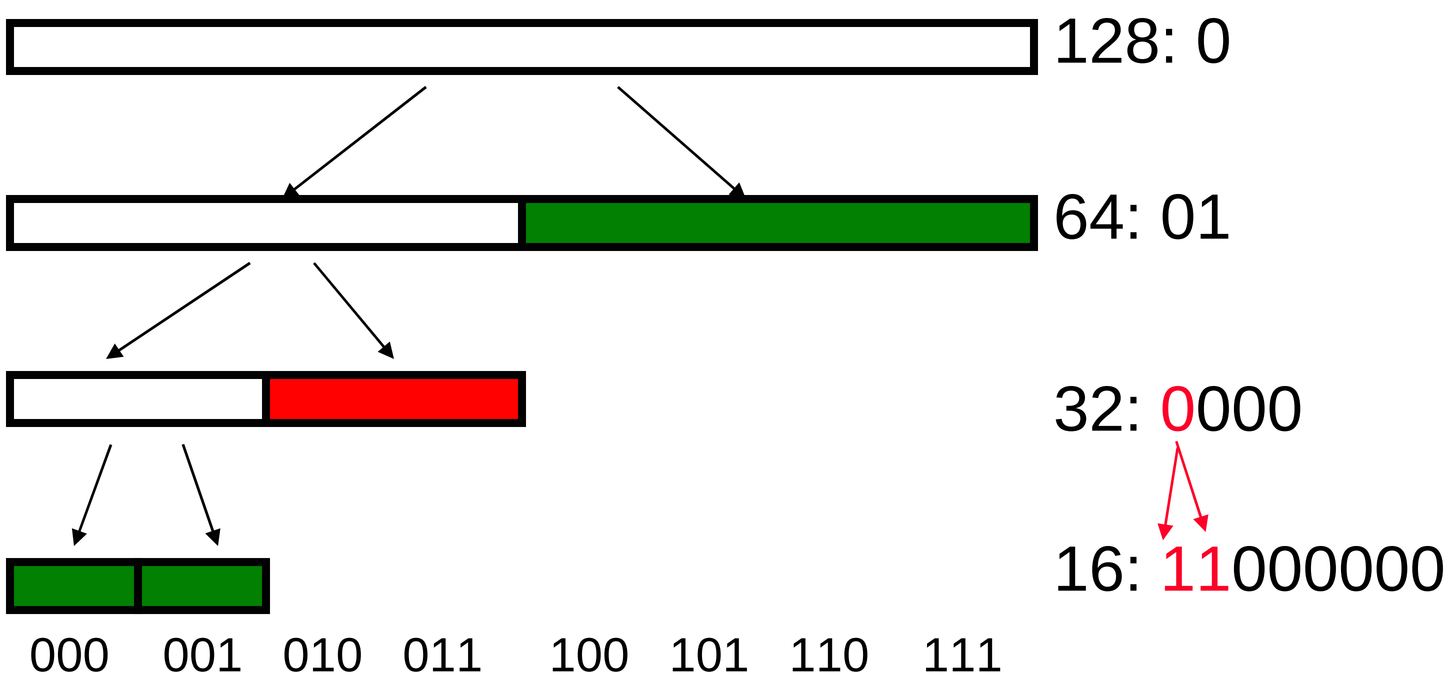
↑
3

Buddy System

- **Legend: FREE ALLOCATED SPLIT**



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1

Buddy System

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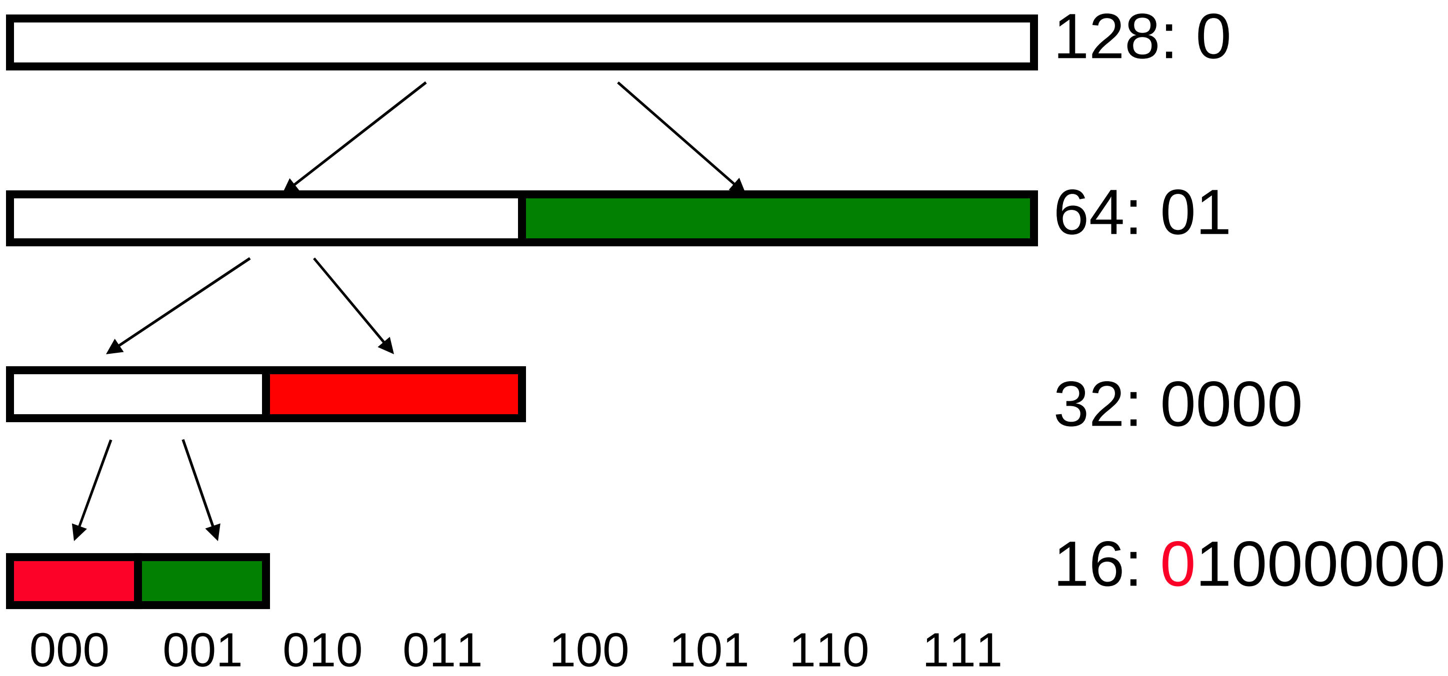


Initial State ➔ Free(001) ➔ Free(000) ➔ Free(111) ➔ Malloc(16)

2

Tracking Memory Usage

- **Depends heavily on the programming language and compiler.**
- **Could have only a single type of dynamically allocated object in memory**
  - **E.g., simple Lisp/Scheme system with only cons cells (61A's Scheme not "simple")**
- **Could use a *strongly typed* language (e.g., Java)**
  - **Don't allow conversion (casting) between arbitrary types.**
  - **C/C++ are not strongly typed.**
- **Here are 3 schemes to collect garbage**

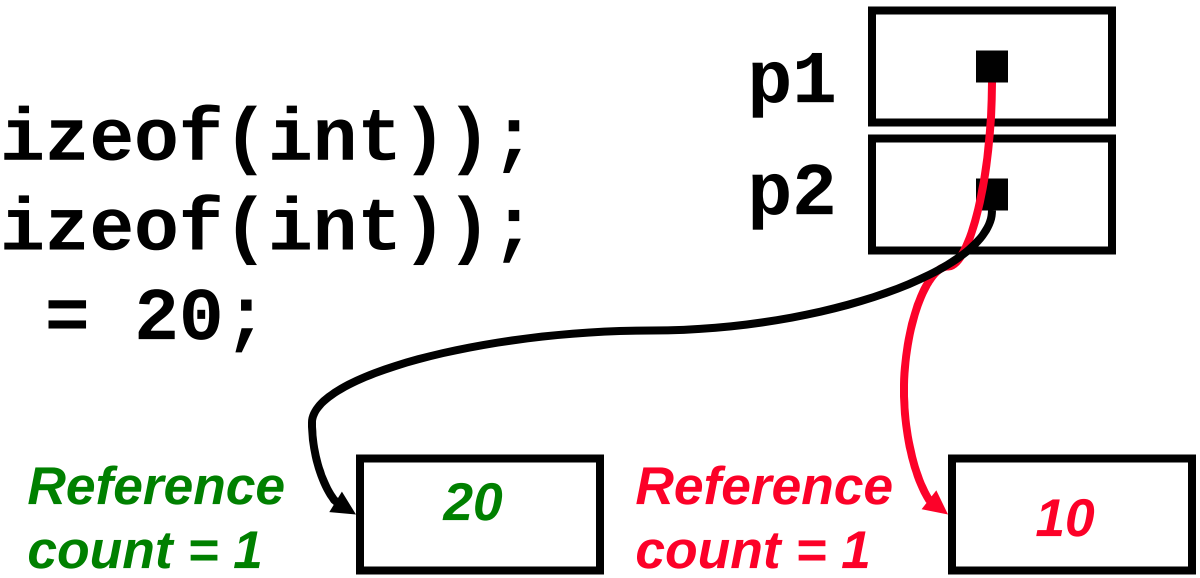
Scheme 1: Reference Counting

- For every chunk of dynamically allocated memory, keep a count of number of pointers that point to it.
- When the count reaches 0, reclaim.
- Simple assignment statements can result in a lot of work, since may update reference counts of many items

Reference Counting Example

- For every chunk of dynamically allocated memory, keep a count of number of pointers that point to it.
  - When the count reaches 0, reclaim.

```
int *p1, *p2;
p1 = malloc(sizeof(int));
p2 = malloc(sizeof(int));
*p1 = 10; *p2 = 20;
```



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p1 = p2;
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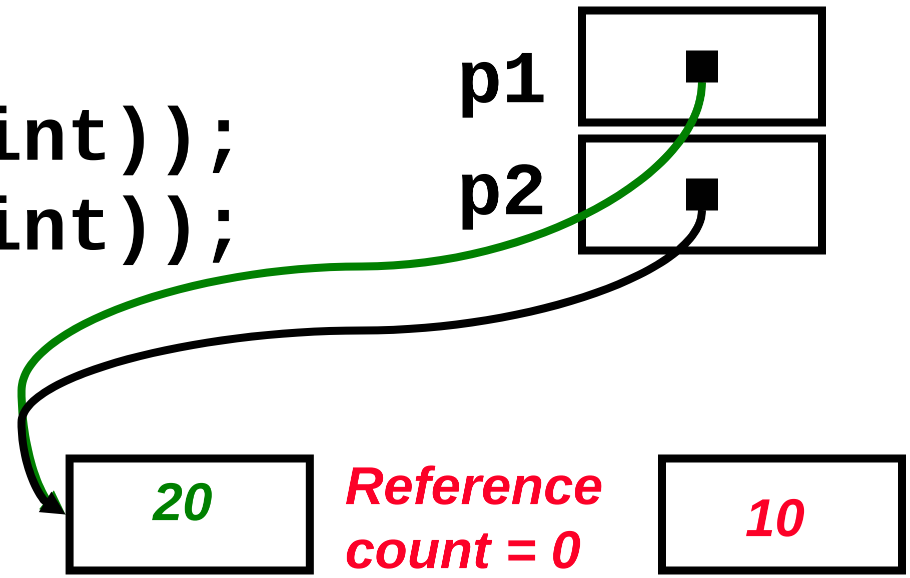


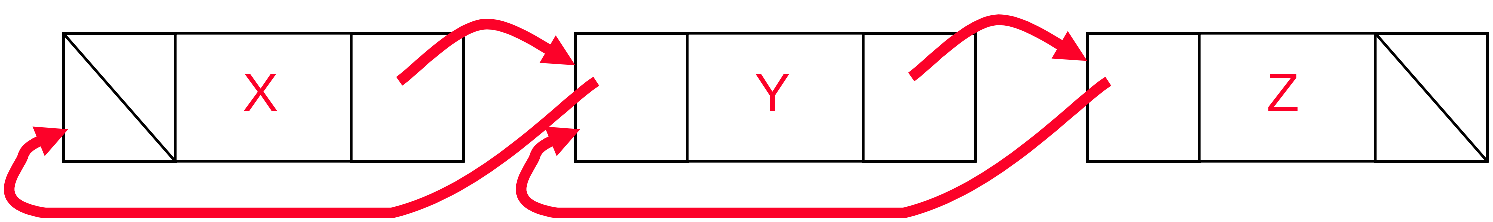
Reference Counting (p1, p2 are pointers)

```
p1 = p2;
```

- Increment reference count for p2
- If p1 held a valid value, decrement its reference count
- If the reference count for p1 is now 0, reclaim the storage it points to.
  - If the storage pointed to by p1 held other pointers, decrement all of their reference counts, and so on…
- Must also decrement reference count when local variables cease to exist.

Reference Counting Flaws

- Extra overhead added to assignments, as well as ending a block of code.
- Does not work for circular structures!
  - E.g., doubly linked list:



Scheme 2: Mark and Sweep Garbage Col.

- Keep allocating new memory until memory is exhausted, then try to find unused memory.
- Consider objects in heap a graph, chunks of memory (objects) are graph nodes, pointers to memory are graph edges.
  - Edge from A to B => A stores pointer to B
- Can start with the root set, perform a graph traversal, find all usable memory!
- 2 Phases: (1) Mark used nodes;(2) Sweep free ones, returning list of free nodes

Mark and Sweep

- Graph traversal is relatively easy to implement recursively

```
void traverse(struct graph_node *node) {
    /* visit this node */
    foreach child in node->children {
        traverse(child);
    }
}
```

- But with recursion, state is stored on the execution stack.
  - Garbage collection is invoked when not much memory left
- As before, we could traverse in constant space (by reversing pointers)

Scheme 3: Copying Garbage Collection

- Divide memory into two spaces, only one in use at any time.
- When active space is exhausted, traverse the active space, copying all objects to the other space, then make the new space active and continue.
  - Only reachable objects are copied!
- Use “forwarding pointers” to keep consistency
  - Simple solution to avoiding having to have a table of old and new addresses, and to mark objects already copied (see bonus slides)

PRS Round 1

A. Of {K&R, Slab, Buddy}, there is no best (it depends on the problem).

B. Since automatic garbage collection can occur any time, it is more difficult to measure the execution time of a Java program vs. a C program.

C. We don’t have automatic garbage collection in C because of efficiency.

Review

- Several techniques for managing heap w/ malloc/free: best-, first-, next-fit, slab,buddy
  - 2 types of memory fragmentation: internal & external; all suffer from some kind of frag.
  - Each technique has strengths and weaknesses, none is definitively best
- Automatic memory management relieves programmer from managing memory.
  - All require help from language and compiler
  - Reference Count: not for circular structures
  - Mark and Sweep: complicated and slow, works
  - Copying: move active objects back and forth

New Topic!

MIPS Assembly Language

Assembly Language

- **Basic job of a CPU: execute lots of *instructions*.**
- **Instructions are the primitive operations that the CPU may execute.**
- **Different CPUs implement different sets of instructions. The set of instructions a particular CPU implements is an *Instruction Set Architecture* (*ISA*).**
  - **Examples: Intel 80x86 (Pentium 4), IBM/Motorola PowerPC (Macintosh), MIPS, Intel IA64, ...**

Instruction Set Architectures

- **Early trend was to add more and more instructions to new CPUs to do elaborate operations**
    - **VAX architecture had an instruction to multiply polynomials!**
- **RISC philosophy (Cocke IBM, Patterson, Hennessy, 1980s) – Reduced Instruction Set Computing**
    - **Keep the instruction set small and simple, makes it easier to build fast hardware.**
    - **Let software do complicated operations by composing simpler ones.**

ISA Design

- Must Run Fast In Hardware ➔ Eliminate sources of complexity.

Software	Hardware
• Symbolic Lookup	➔ fixed var names/#
• Strong typing	➔ No Typing
• Nested expressions	➔ Fixed format Inst
• Many operators	➔ small set of insts

MIPS Architecture

- **MIPS – semiconductor company that built one of the first commercial RISC architectures**

- **We will study the MIPS architecture in some detail in this class (also used in upper division courses CS 152, 162, 164)**
- **Why MIPS instead of Intel 80x86?**
  - **MIPS is simple, elegant. Don't want to get bogged down in gritty details.**
  - **MIPS widely used in embedded apps, x86 little used in embedded, and more embedded computers than PCs**

Most HP LaserJet workgroup printers are driven by MIPS-based™ 64-bit processors.

Assembly Variables: Registers (1/4)

- **Unlike HLL like C or Java, assembly cannot use variables**
  - **Why not? Keep Hardware Simple**
- **Assembly Operands are registers**
  - **limited number of special locations built directly into the hardware**
  - **operations can only be performed on these!**
- **Benefit: Since registers are directly in hardware, they are very fast (faster than 1 billionth of a second)**

Assembly Variables: Registers (2/4)

- **Drawback: Since registers are in hardware, there are a predetermined number of them**
  - **Solution: MIPS code must be very carefully put together to efficiently use registers**
- **32 registers in MIPS**
  - **Why just 32? Smaller is faster**
- **Each MIPS register is 32 bits wide**
  - **Groups of 32 bits called a word in MIPS**

Assembly Variables: Registers (3/4)

- Registers are numbered from 0 to 31
- Each register can be referred to by number or name
- Number references:

  `$0, $1, $2, … $30, $31`

Assembly Variables: Registers (4/4)

- By convention, each register also has a name to make it easier to code
- For now:

  `$16 - $23` ➔ **`$s0 - $s7`**

  (correspond to C variables)

  `$8 - $15` ➔ **`$t0 - $t7`**

  (correspond to temporary variables)

  Later will explain other 16 register names

- In general, use names to make your code more readable

C, Java variables vs. registers

- **In C (and most High Level Languages) variables declared first and given a type**
  - **Example:**
    ```
    int fahr, celsius;
    char a, b, c, d, e;
    ```
- **Each variable can ONLY represent a value of the type it was declared as (cannot mix and match `int` and `char` variables).**
- **In Assembly Language, the registers have no type; operation determines how register contents are treated**

Comments in Assembly

- Another way to make your code more readable: comments!
- Hash (#) is used for MIPS comments
  - anything from hash mark to end of line is a comment and will be ignored
- Note: Different from C.
  - C comments have format
    `/* comment */`
    so they can span many lines

Assembly Instructions

- **In assembly language, each statement (called an Instruction), executes exactly one of a short list of simple commands**
- **Unlike in C (and most other High Level Languages), each line of assembly code contains at most 1 instruction**
- **Instructions are related to operations (=, +, -, *, /) in C or Java**

Administrivia

- Office Hours:

- HW3 Due Monday
- Proj1 Due 7-16
- Midterm 1:
  - Friday, 7/14
  - Probably 11 – 2
  - Room TBD

MIPS Addition and Subtraction (1/4)

- Syntax of Instructions:

  “<op> <dest> <src1> <src2> “

  where:

  op) operation by name

  dest) operand getting result (“destination”)

  src1) 1st operand for operation (“source1”)

  src2) 2nd operand for operation (“source2”)

- Syntax is rigid:
  - 1 operator, 3 operands
  - Why? Keep Hardware simple via regularity

Addition and Subtraction of Integers (2/4)

- **Addition in Assembly**
  - **Example:** `add $s0,$s1,$s2` **(in MIPS)**

    Equivalent to: `s0 = s1 + s2` **(in C)**

    where MIPS registers `$s0,$s1,$s2` are associated with C variables `s0, s1, s2`
- **Subtraction in Assembly**
  - **Example:** `sub $s3,$s4,$s5` **(in MIPS)**

    Equivalent to: `d = e - f` **(in C)**

    where MIPS registers `$s3,$s4,$s5` are associated with C variables `d, e, f`

Addition and Subtraction of Integers (3/4)

- **How does the following C statement?**

```
a = b + c + d - e;
```

- **Break into multiple instructions**

```
add $t0, $s1, $s2 # temp = b + c
add $t0, $t0, $s3 # temp = temp + d
sub $s0, $t0, $s4 # a = temp - e
```

- **Notice: A single line of C may break up into several lines of MIPS.**
- **Notice: Everything after the hash mark on each line is ignored (comments)**

Addition and Subtraction of Integers (4/4)

- How do we do this?

```
f = (g + h) - (i + j);
```

- Use intermediate temporary register

```
add $t0,$s1,$s2     # temp = g + h
add $t1,$s3,$s4     # temp = i + j
sub $s0,$t0,$t1     # f=(g+h)-(i+j)
```

Immediates

- Immediates are numerical constants.
- They appear often in code, so there are special instructions for them.
- Add Immediate:

  `addi $s0,$s1,10` (in MIPS)

  `f = g + 10` (in C)

  where MIPS registers `$s0,$s1` are associated with C variables `f, g`
- Syntax similar to add instruction, except that last argument is a number instead of a register.

Immediates

- There is no Subtract Immediate in MIPS: Why?
- Limit types of operations that can be done to absolute minimum
  - if an operation can be decomposed into a simpler operation, don't include it
  - `addi` ..., -X = `subi` ..., X => so no `subi`
- `addi $s0,$s1,-10` (in MIPS)

  `f = g - 10` (in C)

  where MIPS registers `$s0,$s1` are associated with C variables `f, g`

Register Zero

- **One particular immediate, the number zero (0), appears very often in code.**
- **So we define register zero (`$0` or `$zero`) to always have the value 0; eg**

  `add $s0,$s1,$zero` **(in MIPS)**

  `f = g` **(in C)**

  where MIPS registers `$s0,$s1` are associated with C variables `f, g`
- **defined in hardware, so an instruction**

  `add $zero,$zero,$s0`

  will not do anything!

Peer Instruction Round 2

A. Types are associated with declaration in C (normally), but are associated with instruction (operator) in MIPS.

B. Since there are only 8 local (`$s`) and 8 temp (`$t`) variables, we can't write MIPS for C exprs that contain > 16 vars.

C. If p (stored in `$s0`) were a pointer to an array of `ints`, then `p++;` would be `addi $s0 $s0 1`

"And in Conclusion…"

- In MIPS Assembly Language:
  - Registers replace C variables
  - One Instruction (simple operation) per line
  - Simpler is Better
  - Smaller is Faster
- New Instructions:

  `add, addi, sub`
- New Registers:

  C Variables: `$s0` - `$s7`

  Temporary Variables: `$t0` - `$t9`

  Zero: `$zero`