ANITA'S SUPER AWESOME RECITATION SLIDES

15/18-213: Introduction to Computer Systems

Memory and Caches, 18 Feb 2013

Anita Zhang, Section M

Up to Speed Yet?

- Buflab
  - Due tomorrow, midnight

- Cachelab
  - Out tomorrow, midnight
  - Due Thursday, February 28, 2013, midnight
    - Labs will be going back to regular Thursday due date
  - 10 days to get your C skills back up!

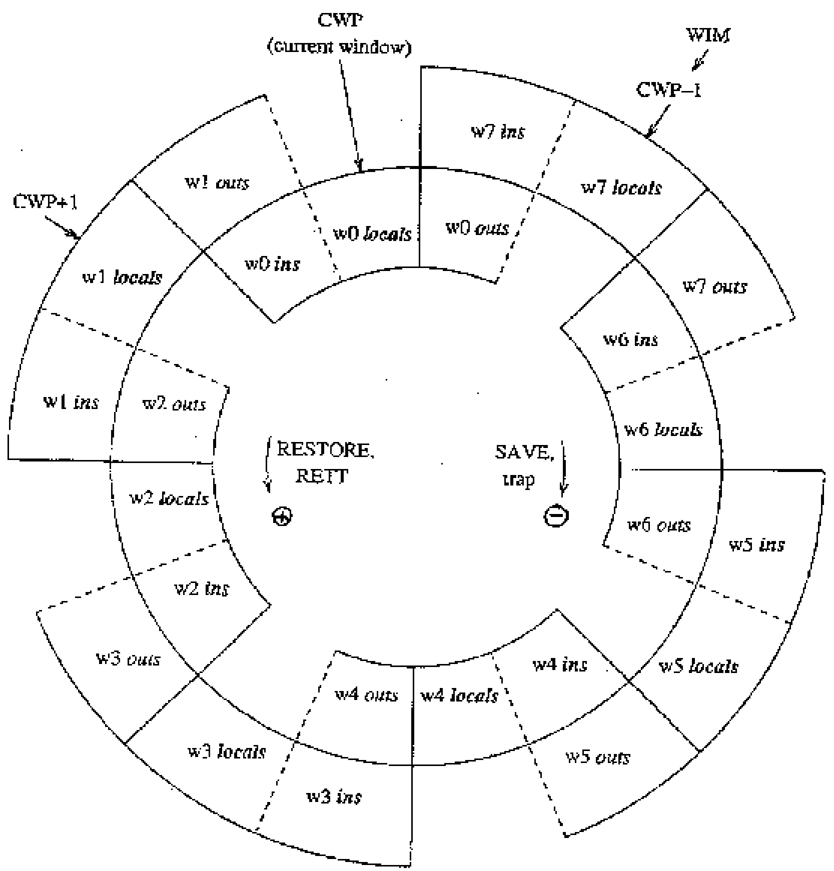
This and That and What

- Alignment
- Memory Organization
- Caching
  - Buzzword: locality
  - Cache organization
- Cachelab
  - Part A – Implement a (hardware) cache simulator
  - Part B – Efficient matrix transpose
  - “Bro, do you even C?” – helpful C stuff

Before we Begin…

- Encouraging Female Reverse Engineers
  - Contest to reverse engineer malicious software
  - And document it with utmost understanding
- Prize
  - Ticket to Symposium on Security for Asia Network (SysScan)
- Details
  - http://addxorrol.blogspot.de/2013/01/encouraging-female-reverse-engineers.html
  - Only women can submit (sorry guys)
  - One of the judges went to CMU!
  - Deadline: 24th of March 2013, 23:59 GMT+1

BAM! CIRCULAR STACK!



SPARC (scalable processor architecture) Architecture

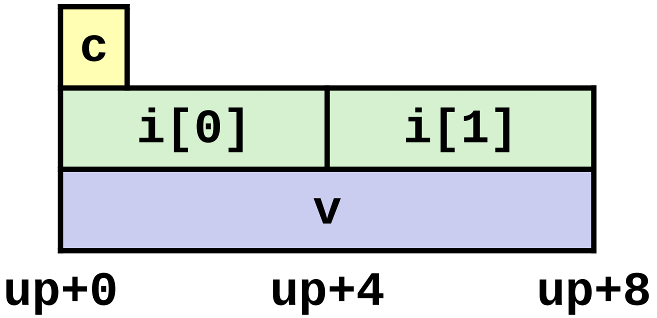
Super Brief on Alignment

- Structs
  - Align according to the largest alignment requirement
    - Must be multiple of K (largest alignment requirement)
    - System dependent alignments requirements
    - Compilers enforce this
  - Overall structure length a multiple of K
    - Optimize length by declaring largest elements first

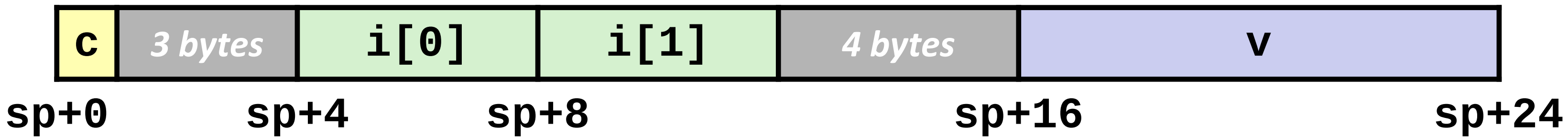
- Unions
  - Size allocated according to largest element
  - Only one field used at a time

Quick Example From Lecture

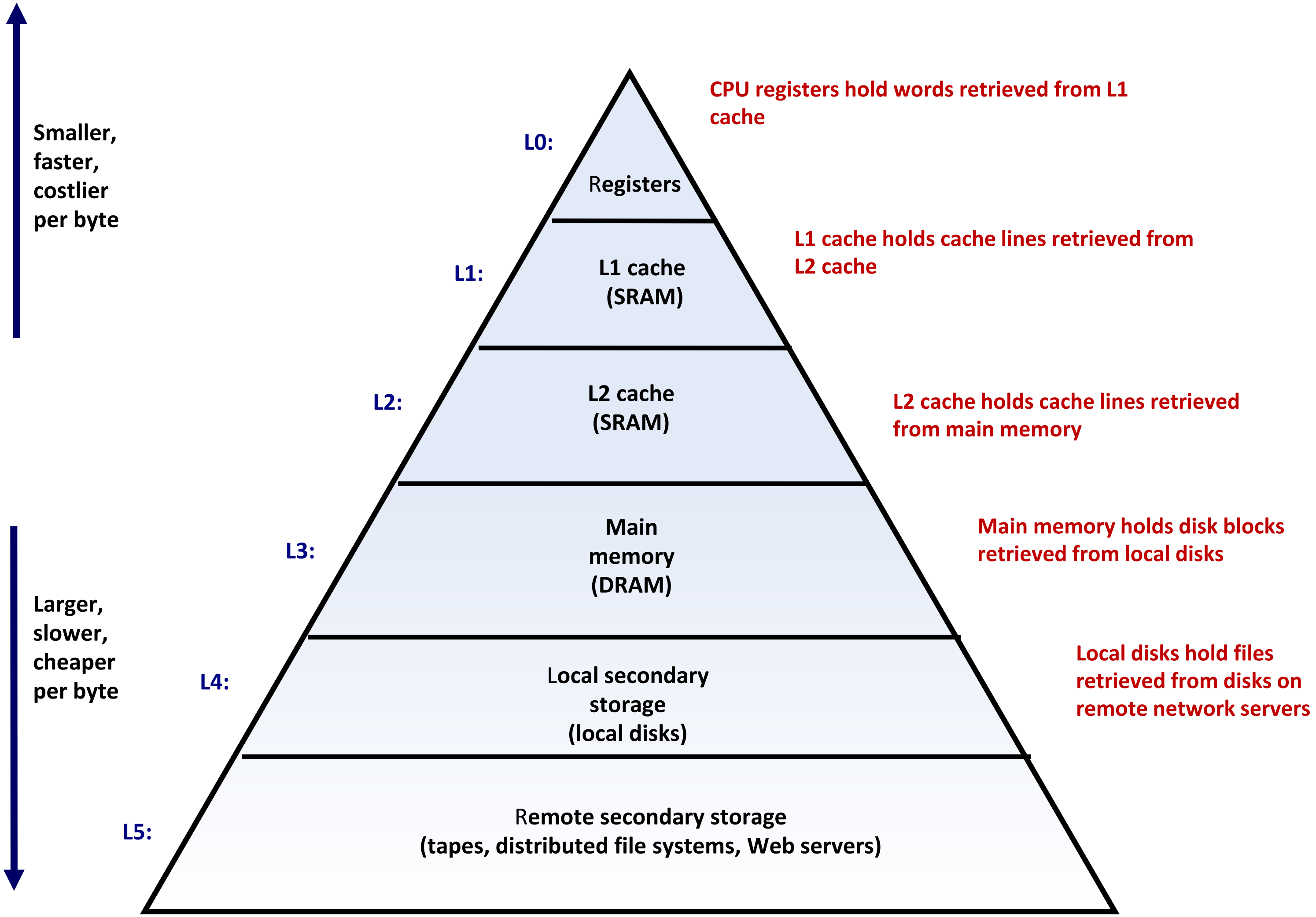
```
union U1 {
  char c;
  int i[2];
  double v;
} *up;
```




```
struct S1 {
  char c;
  int i[2];
  double v;
} *sp;
```



Memory Hierarchy (From Lecture)



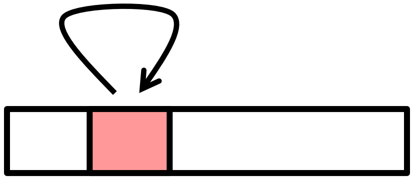
SRAM VS DRAM

- SRAM
  - Faster (L1 Cache: 1 CPU cycle)
  - Smaller (L1 in kilobytes; L2 in megabytes)
  - More expensive and “energy-hungry”

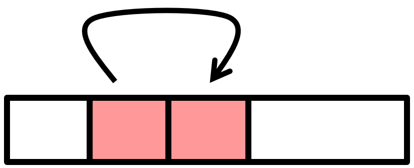
- DRAM (Main memory)
  - Relatively slower (hundreds of CPU cycles)
  - Larger (Gigabytes)
  - Cheaper

LOCALITY

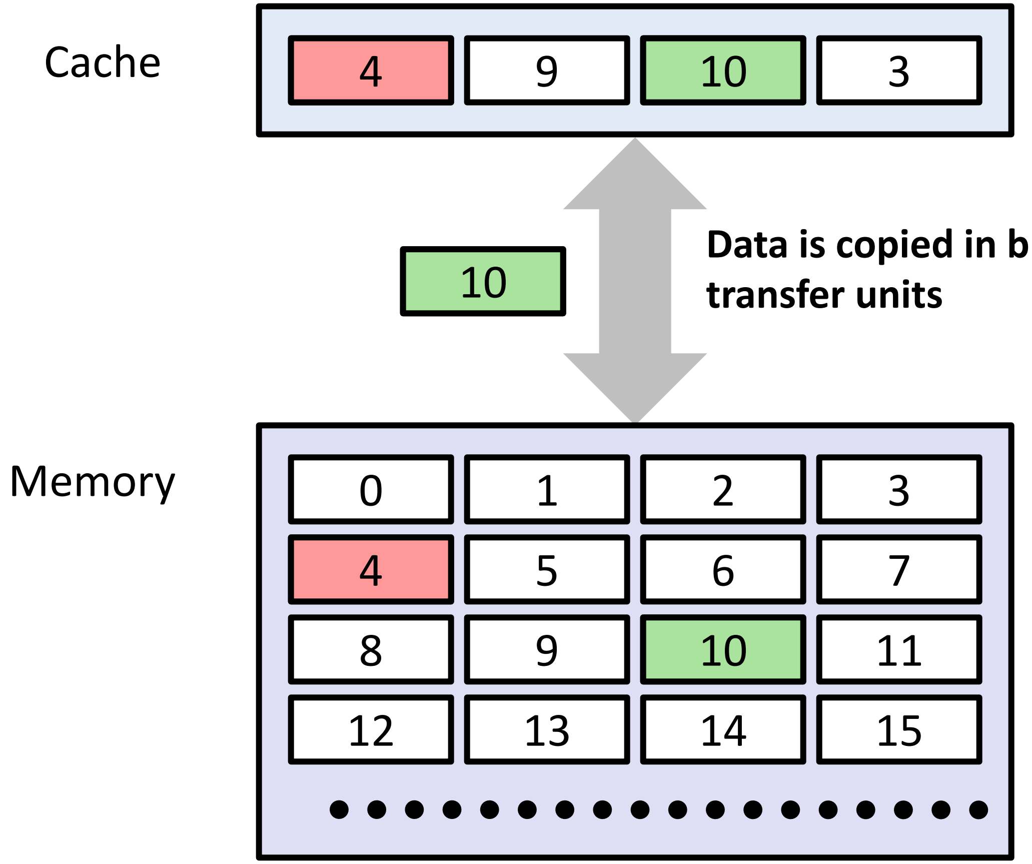
- Temporal locality
  - Recently referenced items are likely to be referenced again in the near future
  - After accessing address X in memory, save the bytes in cache for future access



- Spatial locality
  - Items with nearby addresses tend to be referenced close together in time
  - After accessing address X, save the block of memory around X in cache for future access



General Caching (from lecture)



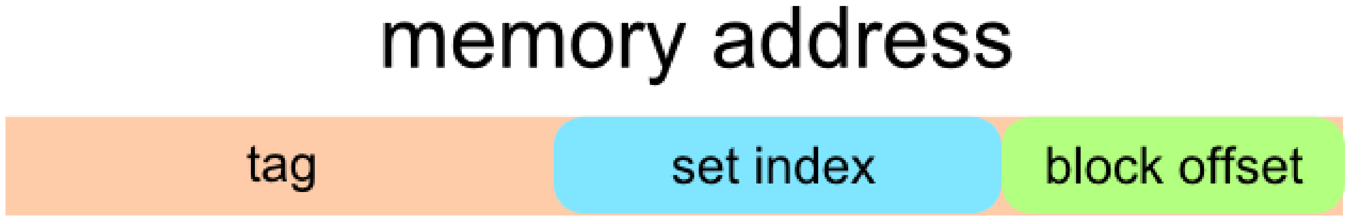
Smaller, faster, more expensive memory caches a subset of the blocks

Data is copied in block-sized transfer units

Larger, slower, cheaper memory viewed as partitioned into "blocks"

Address Division in Caches

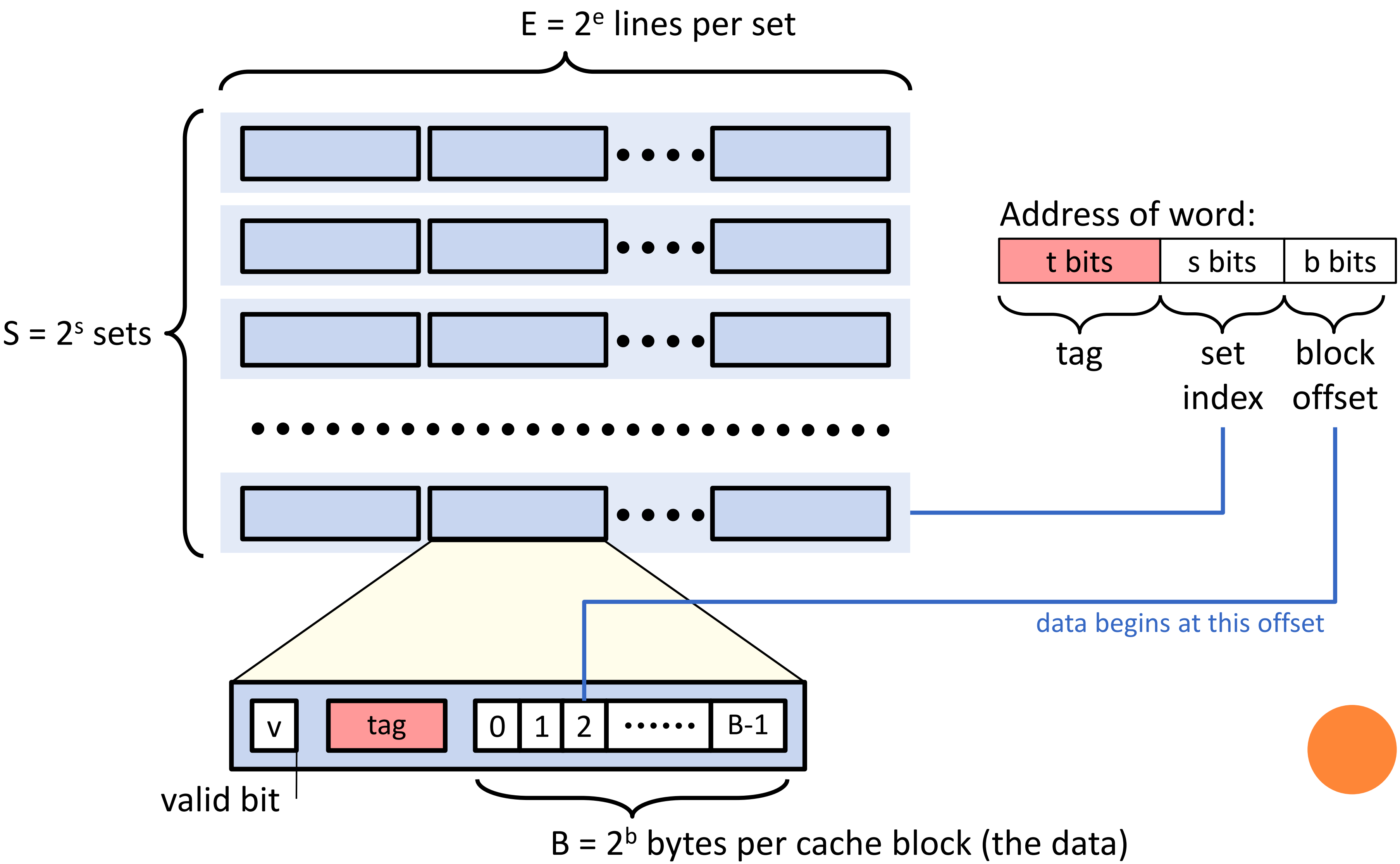
- On the Sharks, addresses are 64-bits
- Dividing a memory address
  - Block offset: b bits
  - Set index: s bits



Caches

- A cache is a set of 2^s cache sets
- A cache set is a set of E cache lines
  - E is called associativity
  - If E=1, it is called "direct-mapped"
- Each cache line stores a block
  - Each block has 2^b bytes

Visual Cache Terminology



Cache Lab Part A

- Cache Simulator
  - Implement for variable s, b, and E values
    - Values read in from a trace file (at runtime)
  - Least Recently Used (LRU) Policy

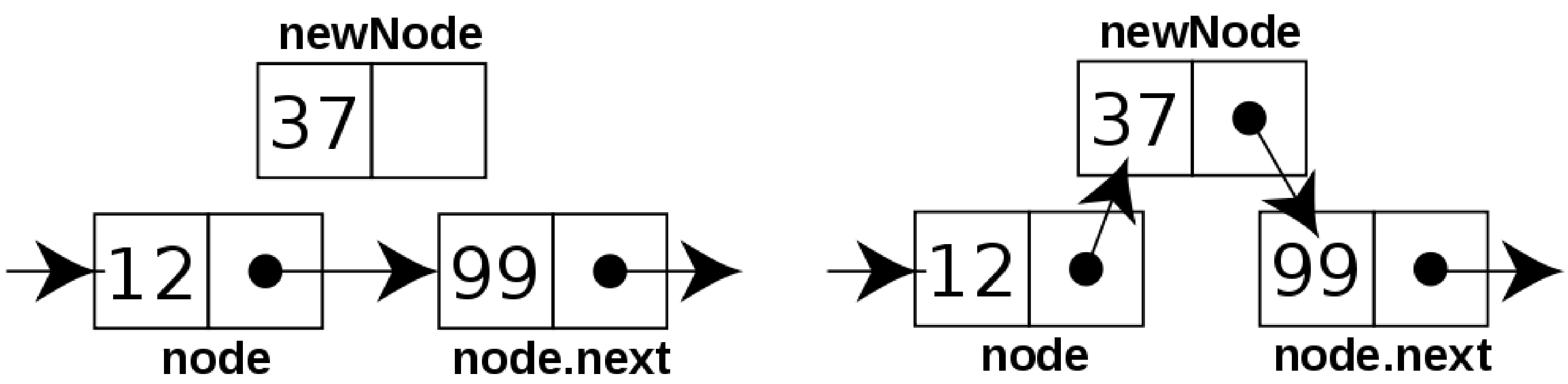
- Cache Simulator != Cache
  - This simulator does NOT store memory contents
  - We do NOT care about block offsets here
  - Your goal: implement the policy and count the number of hits, misses, and evictions

General Simulator Design Hints

- A cache is just 2D array of cache lines:
  - `struct cache_line cache[S][E];`
  - $S = 2^s$ is the number of sets
  - E is associativity
- Each `cache_line` has:
  - Valid bit
  - Tag
  - LRU counter

Anita's Favorite Data Structure

- Linked lists
  - "The only data structure you will ever need"
  - (Heavily) used in cache and malloc lab
  - A lesson on linked list in the credits page



Food for Thought/ Other Designs

- How necessary is the LRU counter?
  - We have the power to insert nodes wherever we want
    - So why use a counter?

- As a C programmer, implementing a linked list should be second nature
  - 5-10 minutes tops
  - The same deal every time
    - Pointers to each node
    - Traversal helper functions
    - Making the right checks

Cachelab Part B

- Efficient matrix transpose
  - Goal: Increasing locality via blocking

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

1	5	9	13
2	6	10	14
3	7	11	15
4	8	12	16

Cachelab Part B

- Cache:
  - 1 kilobytes of cache
  - Directly mapped (E=1)
  - Block size is 32 bytes (b=5)
  - S = 32 sets (s=5)

- Test Matrices:
  - 32 x 32, 64 x 64, 61 x 67
  - You only need to optimize for these sizes

"Bro, Do You Even C?"

- In this section:
  - Warnings are errors
  - Headers
  - Useful C functions

Warnings are Errors

- Strict compilation flags
  - Avoid potential errors that are hard to debug
  - Learn good habits from the beginning

- Add "-Werror" to your compilation flags

- DO NOT ignore the compiler errors

What About Headers?

- Remember to include files that we will be using functions from

- If function declaration is missing
  - Find corresponding header files
  - `unix> man` *`function-name`*
    - Skim the man pages, they'll tell you what you need to know

FUNCTION 1: GETOPT

- `getopt` automates parsing elements on the unix command line
  - Typically called in a loop to retrieve arguments
  - Use a switch statement to handle options
  - Returns -1 when there are no more arguments

- Must include the header file `unistd.h`

FUNCTION 1: GETOPT

- Switch statement used on the (local) variable holding the return value from getopt
  - Each command line input can be handled separately
  - optarg – Points to the value of the option argument
    - This is set by the getopt function

- Food for thought
  - How do we handle invalid inputs?

Function 1: getopt Example

- Suppose we had an executable called “foo”
  - Example call from shell: `unix> ./foo -x 1`

- Next slide: Parsing the argument to the x option
  - Notice: We passed in an int which is read as a char *
  - We use `atoi` to convert the string to an int

Function 1: getopt Example

```
int main(int argc, char** argv){
    int opt, x;

    /* looping over arguments */
    while(-1 != (opt = getopt(argc, argv, “x:")))){

        /* determine which argument it’s processing */
        switch(opt) {
            case 'x':
                x = atoi(optarg);
                break;
            default:
                printf(“wrong argument\n");
                break;
        }
    }
}
```

Function 2: fscanf

- The `fscanf` function is just like `scanf`
  - But it can specify a stream to read from
  - `scanf` always reads from stdin
- Parameters:
  - File pointer
  - Format string with information on how to read file
  - Variable number of pointers to with locations for storing data from file
- Typically use in a loop until it hits the end of file
- `fscanf` will be useful in reading from the trace files

Function 2: fscanf Example

```
FILE * pFile; // pointer to FILE object

/* open file for reading */
pFile = fopen ("myfile.txt", “r");

int x, y;
char c;

/* read two ints and a char from file */
while(fscanf(pFile, “%d %d %c”, &x, &y, &c) > 0){
    // Do stuff
}

fclose(pFile); // remember to close file when done
```

Function 3 and 4: malloc/free

- Use `malloc` to allocate memory on the heap
  - Returns a pointer to location in memory
- Always free what you `malloc`
  - Or you'll suffer from memory leaks
- Example usage:
  - `int *pointer = malloc( sizeof(int) );`
  - `free(pointer);`
- DO NOT free memory you didn't allocate
  - This includes double free-ing

Style and Tips for Life

- Read the style guideline
  - "But I already read it!"
  - Good, read it again.

- Check for failures and errors ALWAYS
  - Functions don't always succeed
  - What happens when a system call fails?

- Common cases of failure:
  - Not checking the return of `malloc`
  - Not handling invalid inputs
  - Generally, not checking returns of functions

I Stole From These Places

- [Understanding the SPARC Architecture]
- [Wikipedia: Linked Lists]
- [C Linked List Example]
- [getopt from GNU]
- [fscanf from CPlusPlus.com]