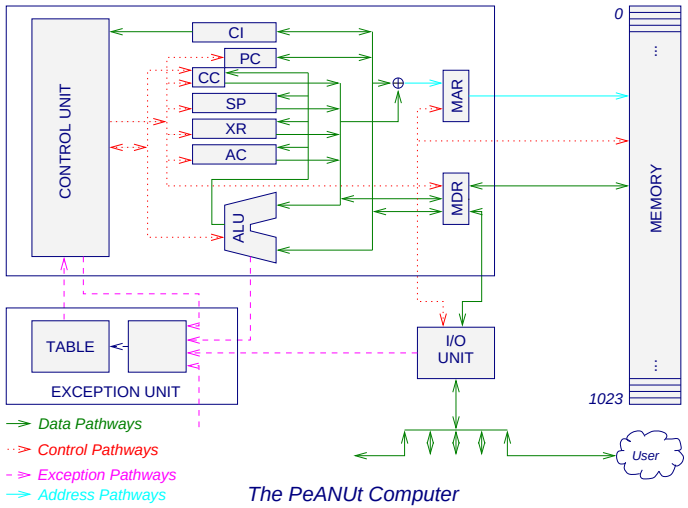
PeANUt Repetition and Virtual Memory

- ref: [PeANUt Spec, sect 3]; additionally [O'H&Bryant, sect 10.1–10.7] or [Null&Lobur, sect 6.5]
- PeANUt repetition
  - architecture
  - instructions and addressing modes
  - the stack and procedures
  - macros and traps
- virtual memory concepts
  - introduction
  - paging

PeANUt Repetition – Architecture



The PeANUt Computer

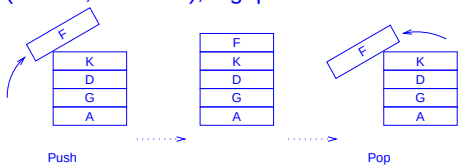
PeANUt Repetition – Instructions and Addressing Modes

- all instructions are 16 bits long (one memory cell)
- each instruction has *up to* three components:
  1. an opcode
  2. an (operand specifier (opspec) (in lowermost 10 bits)
  3. a mode (addressing mode) (in top 3 bits)
- the opcode identifies its operation [PeANUt Spec, table 1]
- the operand is the data upon which the instruction operates
  - some instructions do not need an operand, some have an implicit one
- there are 5 addressing modes:

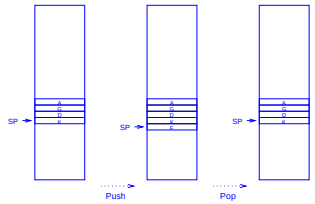
1)	immediate:	(#)	OP = opspec	`load #20`
2)	direct:		AOP = opspec OP = Memory[AOP]	`load 20`
3)	stack:	(!)	AOP = opspec + SP OP = Memory[AOP]	`load !-1`
4)	indexed:	(∗)	AOP = opspec + XR OP = Memory[AOP]	`load *20`
5)	indirect:	(@)	AOP = Memory[opspec] OP = Memory[AOP]	`load @20`

PeANUt Repetition – The Stack and Function Calls

- a fundamental programming concept! Hence *hardware* support needed (e.g. SP, !)
- uses a (reserved) part of (normal) memory called the stack
  - is accessed *LIFO* (Last In, First Out), e.g. pile of books



- can be efficiently implemented as the memory pointed to by the stack pointer (SP)

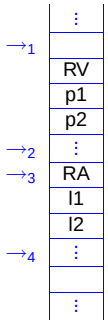


- enables return of control to caller & passing parameters and return values

PeANUt repetition – Procedure Call Conventions

- determines order of data in the stack frame
- example C function declaration:

```
int P(int p1, int p2, ...) {
  int l1, l2, ...;
  ...
}
```



return value (if any)

parameters

return address

local variables (if any)

→1 SP just before (explicitly) pushing parameters & just after popping them

→2 SP just before executing call P and just after executing P's ret

→3 SP just before executing 1st instruction in P and just before executing P's ret

→4 SP inside body of P, after (explicitly) allocating space for local variables (references to parameters, return value & local variables are relative to this position)

PeANUt Repetition – Macros

- context: important (yet simple) computational concept
- widely used in the C programming language
- neither instructions nor procedures! Essentially, just a 'shorthand'
- exist only in the assembly language level, i.e. are expanded by the assembler

  (C macros exist only in the C language)
- are best for 'straight-line' code
- can be good programming style, especially if they correspond to meaningful (high-level language) operations (e.g. printing strings in transpose.ass)
- must be defined at the top of the program, used later (e.g. macro.ass)

PeANUt Repetition – Traps

- there is a special instruction called **`trap`**
- used to have PeANUt perform a 'operating system' service
- depending on the trap's operand, some particular operation will be performed, e.g.:
  - **`trap #1`** Halt: tells the PeANUt to stop execution
  - **`trap #2`** Get: Allows you to read a character from keyboard
  - **`trap #3`** Put: Allows you to print out a character
- some are user-definable/modifiable (lecture P9)
- some relate to virtual memory

Reflection for COMP2300: to PeANUt or not to PeANUt? Possible alternatives:

- MARIE [Null&Lobur, Ch 4] – no indexed or stack mode :(
- Pep/8 [Computer Systems, J.S. Warford] – much like PeANUt
- 8088 Assembler/Simulator [Tanembaum, Appendix C] – subset of the x86 assembly language
- a simplified RISC machine?

Virtual Memory

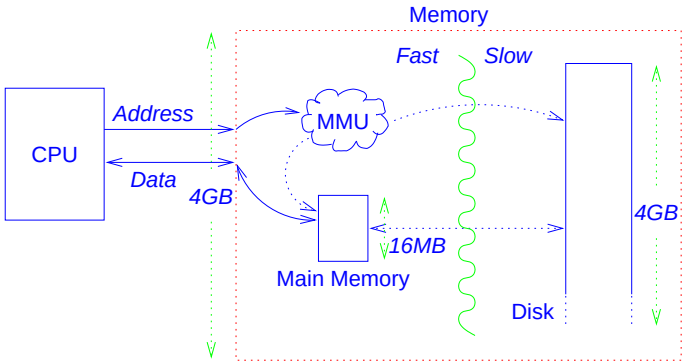
- motivation: (multiple) users regularly need to run jobs whose capacity exceeds that of physical memory (main memory)
  - one of the first (and most important) instances of virtualization
  - also, in a multiprocessing environment, each program 'sees' memory in the same way, regardless of where it is executing in physical memory
- virtual memory is a technique whereby program-addressable memory is made to appear to be larger than physical memory
- needed because there is a memory hierarchy:
  - many different mediums for the storage of data
  - generally, there is a *trade-off* between speed and capacity (fast memories tend to be small; large memories tend to be slow)

medium	access time (nsec)	typical size
registers	∼10	< 1 KB
cache memory	∼25	< 2 MB
physical memory	100	< 2 GB
disk	20,000,000	> 10 GB

[O'H&Bryant, fig 6.21]

Virtual Memory – Nomenclature

- address space: range of addresses accessible to programmer
- logical/virtual addresses: addresses as seen by the programmer
- physical addresses: actual addresses in main memory
- the Memory Management Unit (MMU) performs this translation



Paging

- how do we share main memory between competing chunks of the (virtual memory) address space?
- one solution is called paging
  - break all memory into equal sized chunks called pages
  - when accessing a virtual address, check if the corresponding page is in main memory
    (if not, move it into main memory and then access it)
- exploits locality of (address) references:
  - memory accesses tend not to be random (in a program, they are often in a sequence)
    - consider in particular accesses involved with instruction fetching
  - rule of thumb: a program spends about 90% of its time in only 10% of the code

Paging Issues

- how big should a page be? Influenced by disk technology
- what does main memory look like? It consists of a mixed group of pages, with each page occupying a slot (page frame) (e.g. PeANUt VM)
- what does (disk) virtual memory look like? It consists of all of the pages
- programmer's view of paging:
  - is oblivious of it: all program addresses are virtual
  - can only see performance degradation (when paging requires many disk accesses, called swapping)

Virtual Memory Issues

- what pages should be resident in main memory (MM) at any time?
  - the most used pages
  - different paging policies dictate how 'most used' is defined
- data consistency:
  - upon a page fault (access of data in a page not currently in physical memory), a page currently in main memory usually has to be removed:
    - if simply thrown out, data may be lost
    - if always written back to disk (upon each `store`), will be too slow!
  - solution: write it back to disk, if it has been written to (made dirty)
    - hence the MMU must record this for each page ('Dirty bit')