Machine Called Computer

Part 5

Fetch-decode-execute,

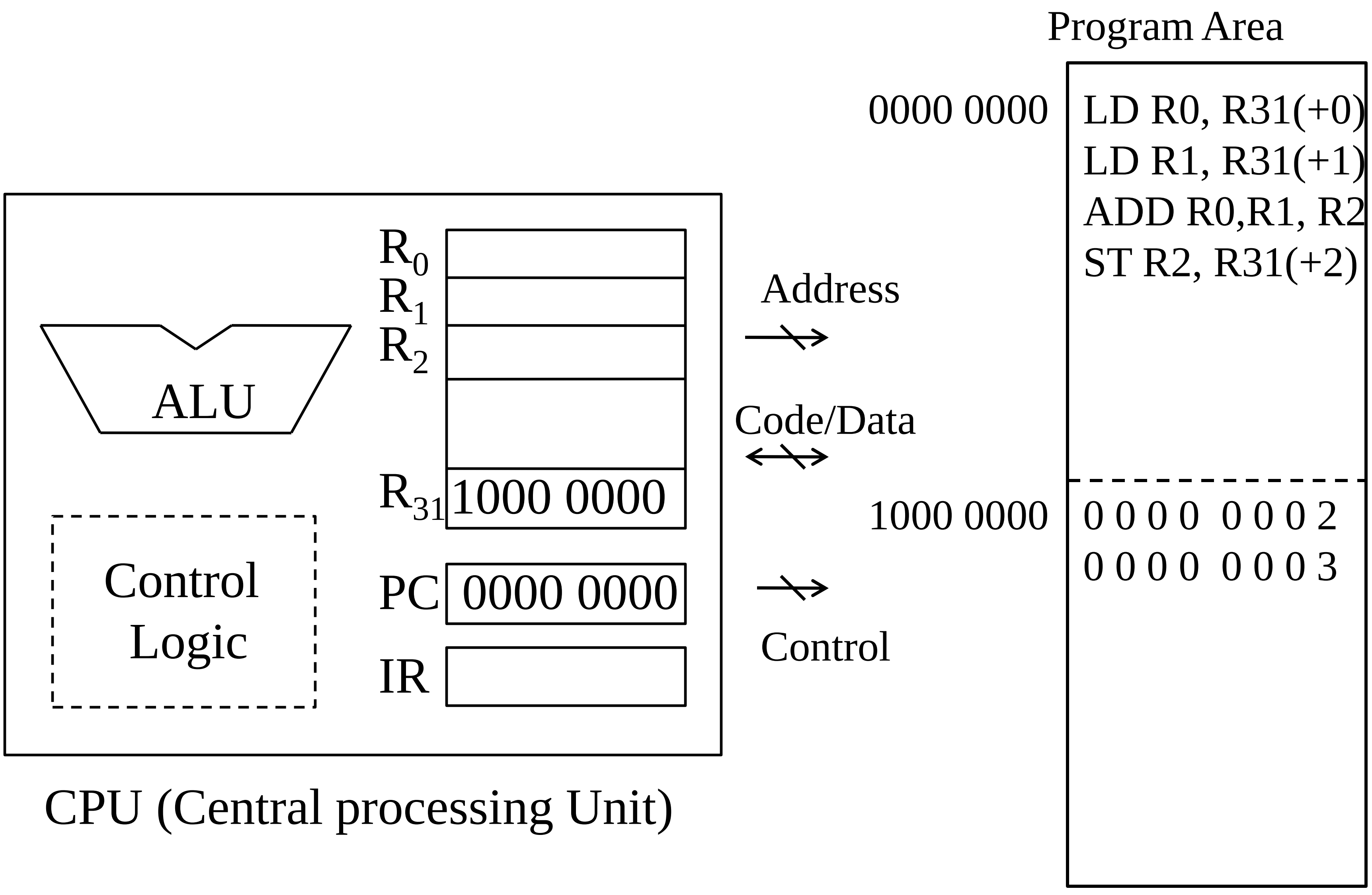
Stored Program Computer,

ISA (Instruction Set Architecture)

References:

1. Computer Organization and Design & Computer Architecture, Hennessy and Patterson (slides are adapted from those by the authors)

To Start Program Execution

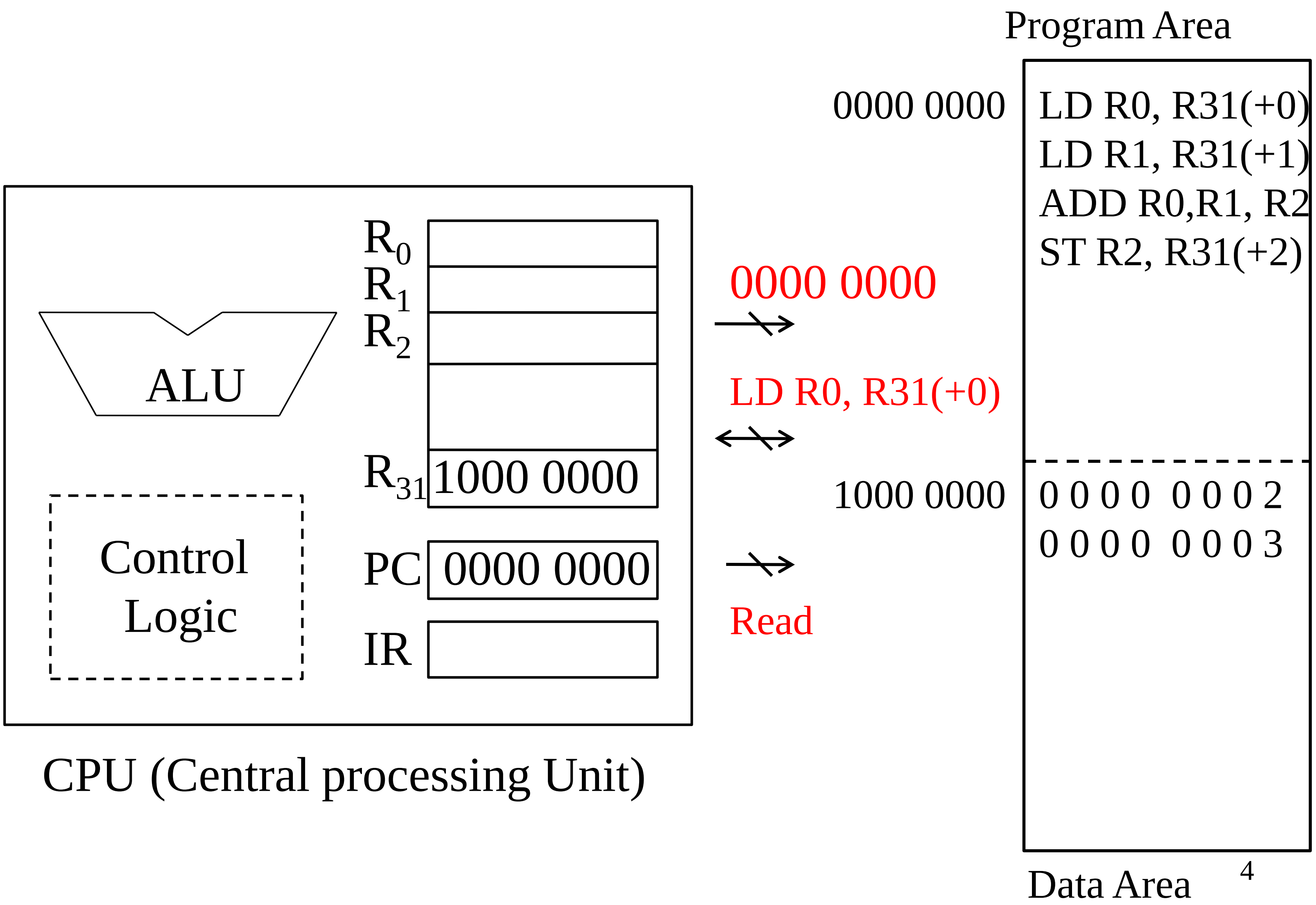


CPU (Central processing Unit)

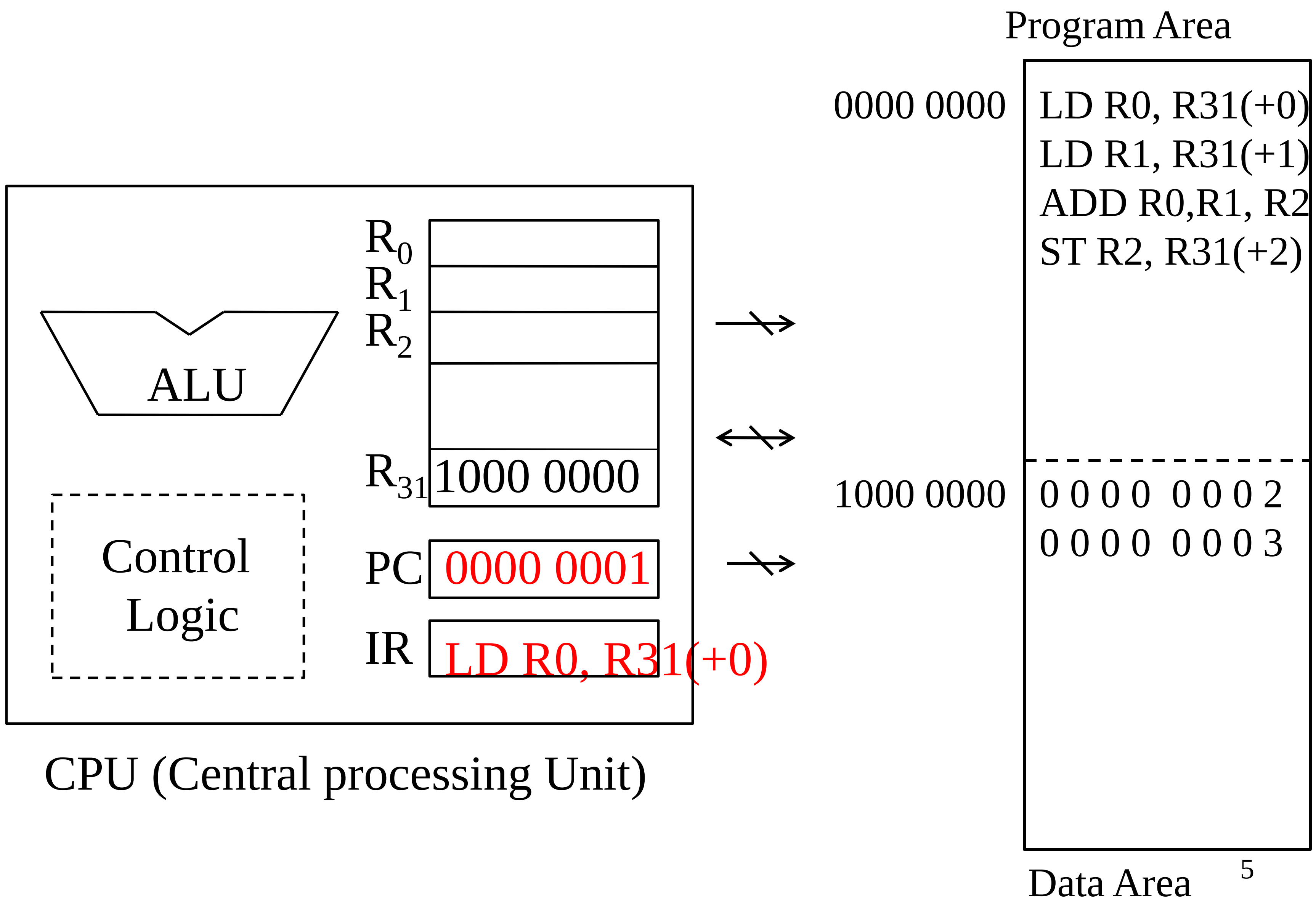
Program Execution

- Set up for execution
  - Program at known location
    - PC (program counter) = $0000\ 0000_{HEX}$
      - † PC: address of instruction to execute next
  - Data at known location
    - R31 = $1000\ 0000_{HEX}$
- Program for adding two numbers
  - 4 machine instructions

Step 1: Instruction Fetch (IF)



Step 1: Instruction Fetch (IF)



Step 2: Instruction Decode (ID)

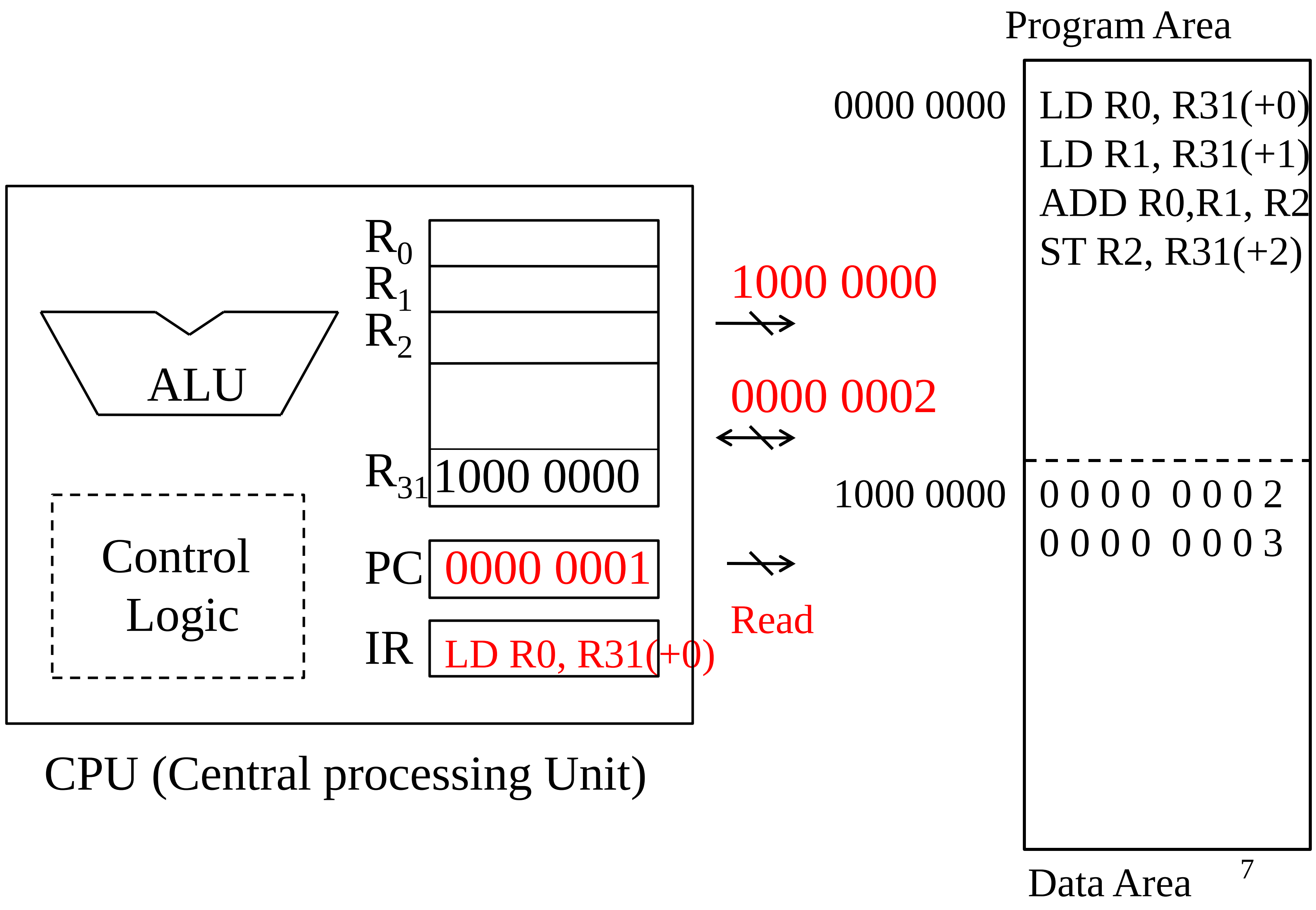
- Control logic in CPU
  - Examine the content of IR (i.e., fetched instruction)
  - Understand what it is

    LD, R0, R31(0)

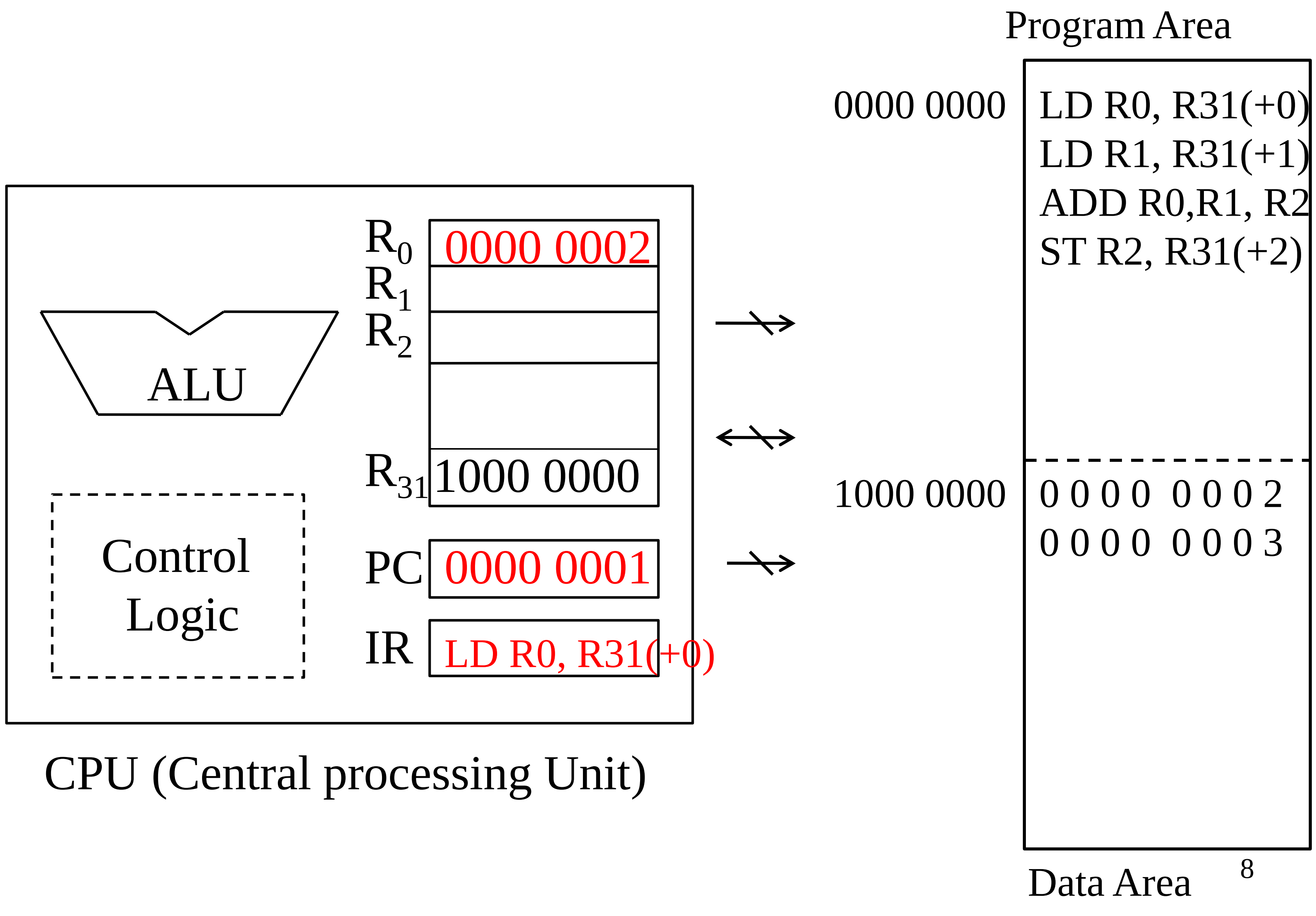
    $R0 \leftarrow M[R31 + 0]$

    $R0 \leftarrow M[1000\ 0000]$
  - Read what is in memory address 1000 0000 and copy it to register 0
    - Why not use absolute address ("LD, R0, 10000000")?

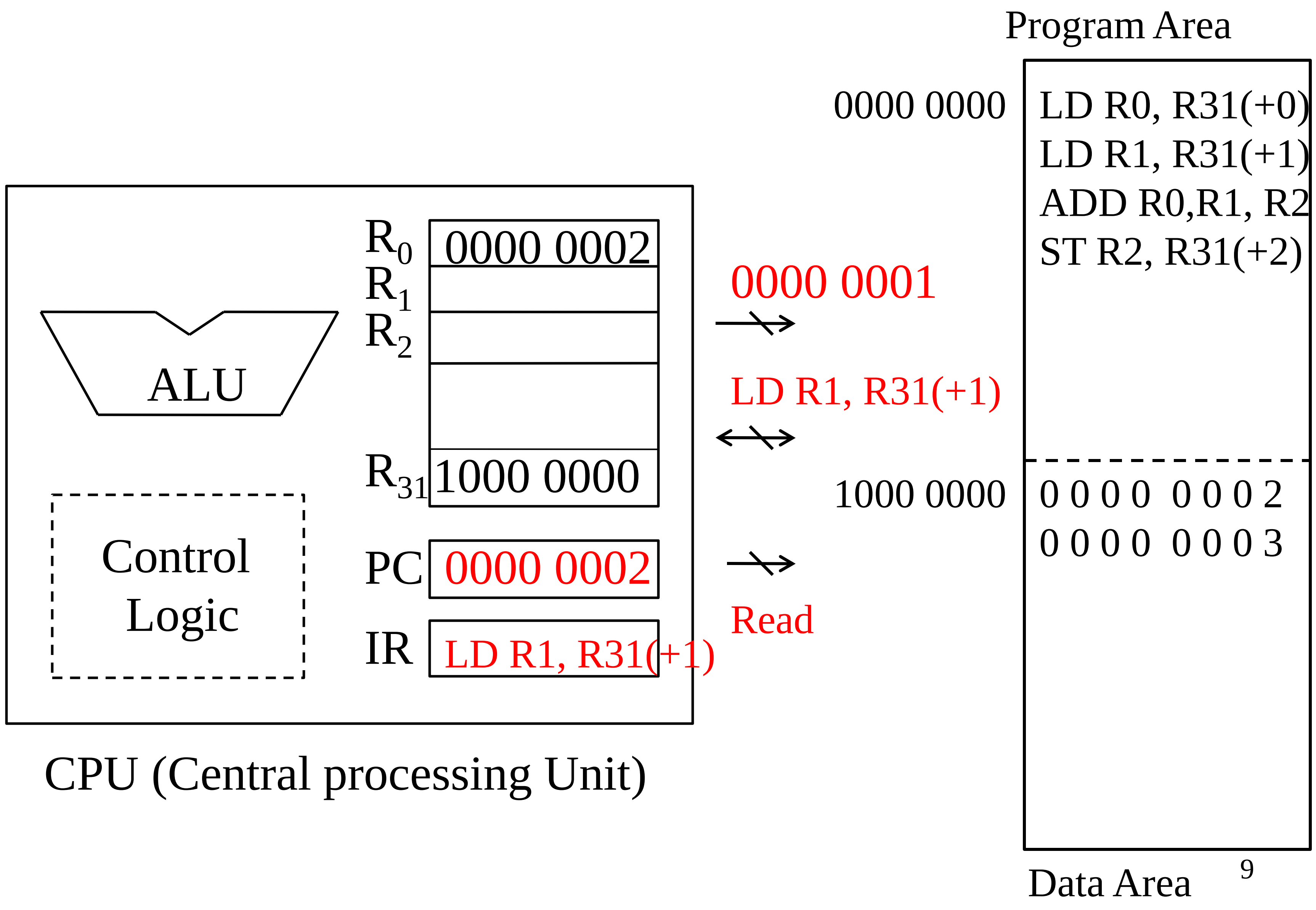
Step 3: Instruction Execute (EX)



Step 3: Instruction Execute (EX)

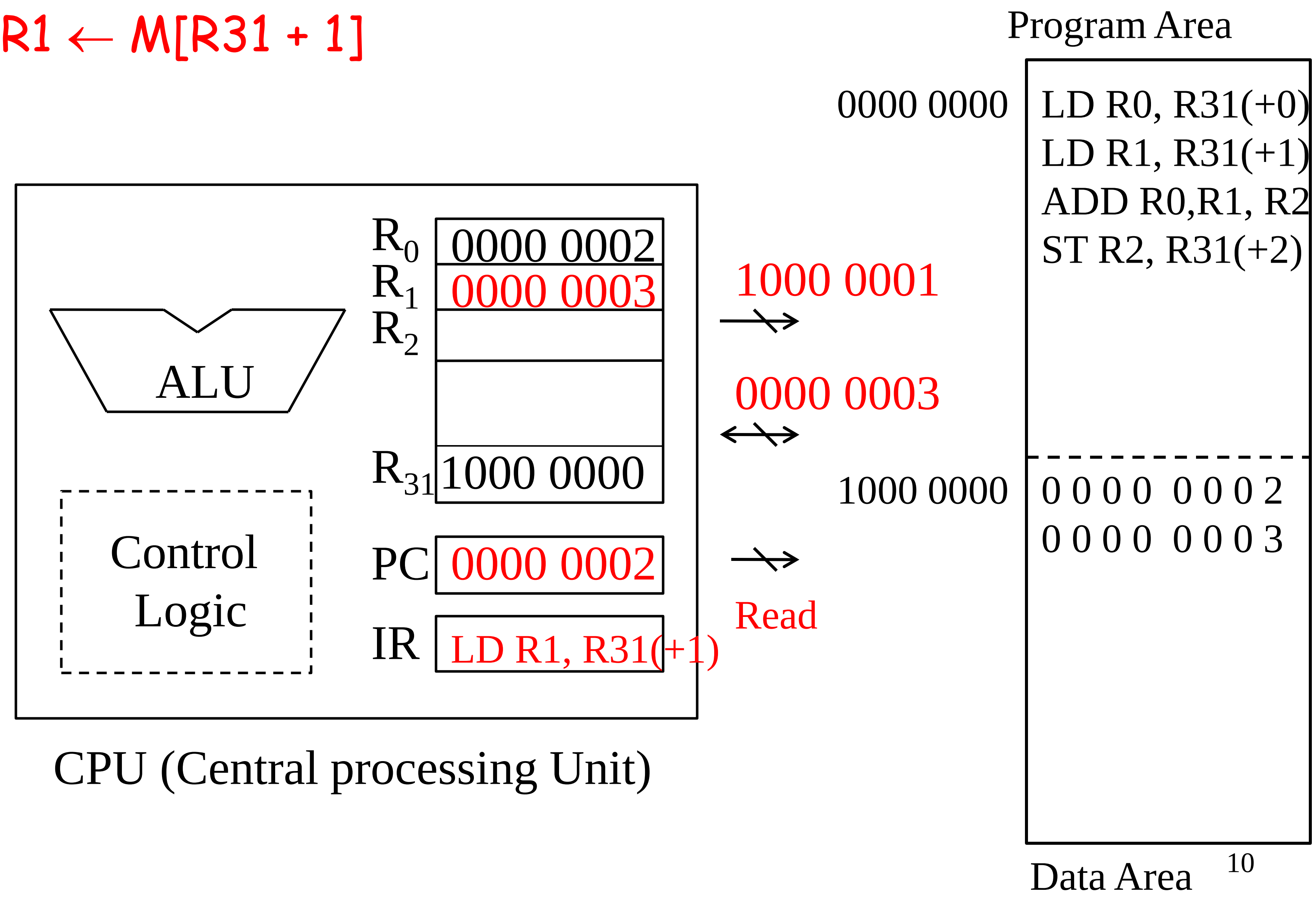


Fetch of 2nd Instruction

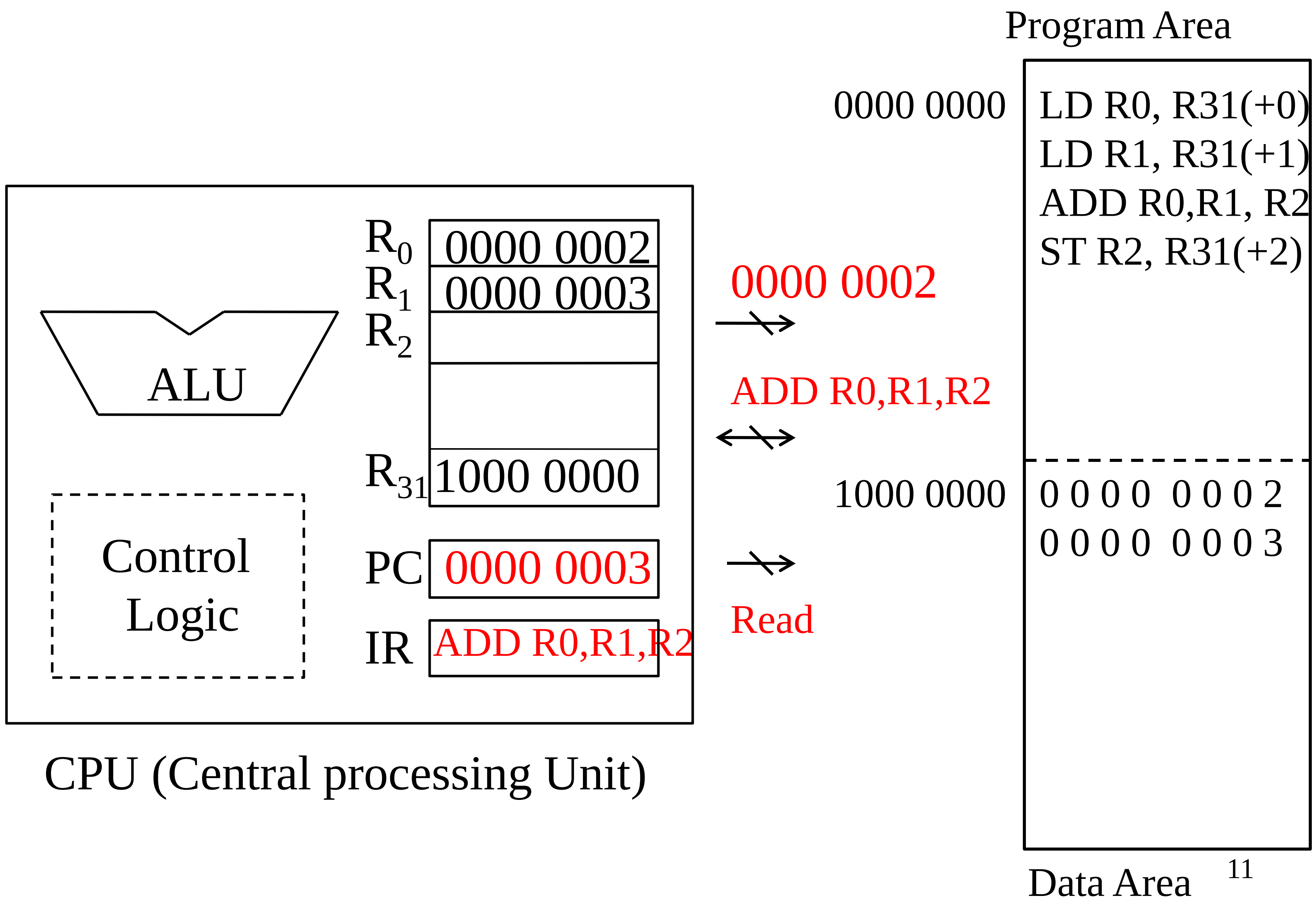


Decode and Execute 2^{nd} Instruction

$R1 \leftarrow M[R31 + 1]$



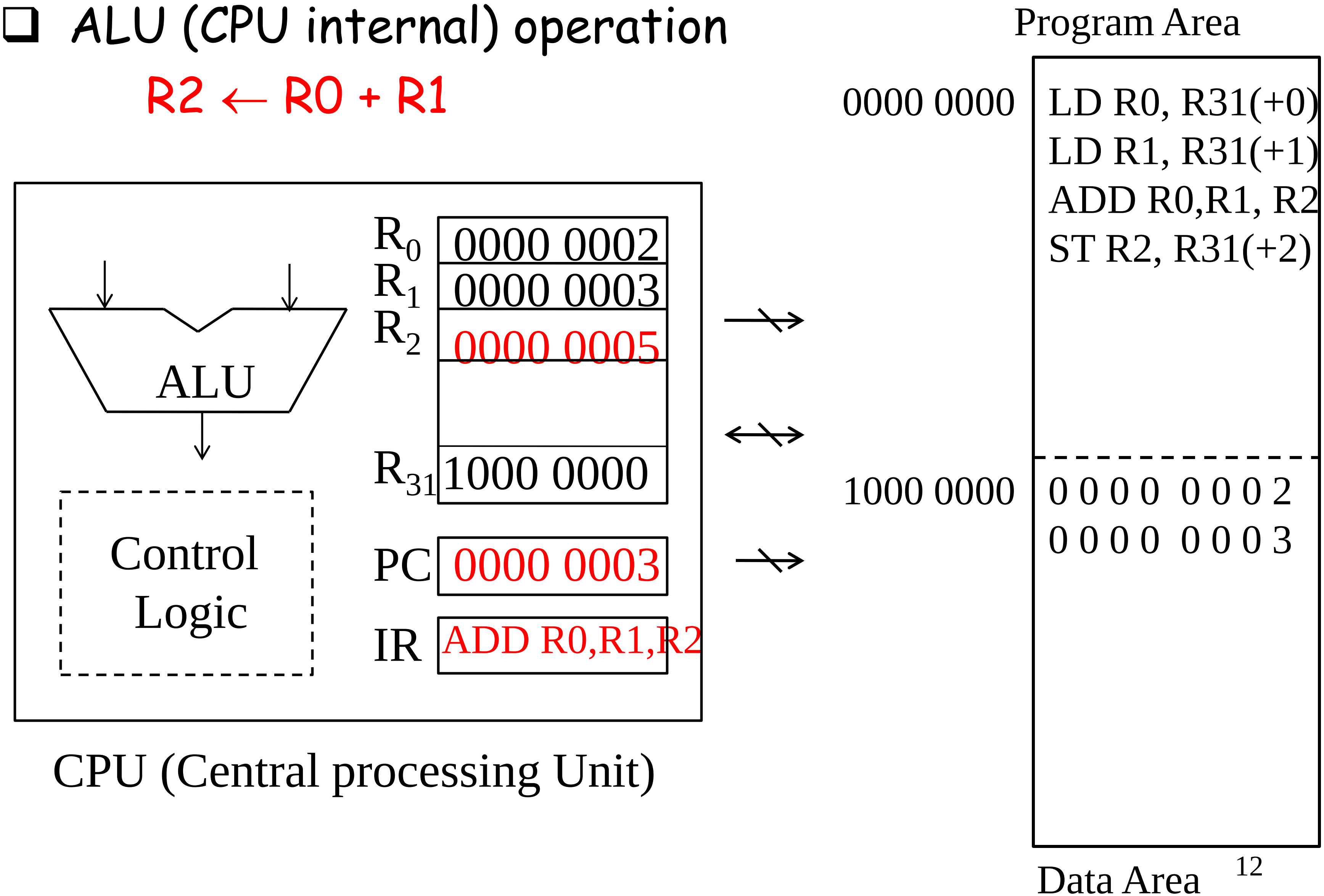
Fetch of 3rd Instruction



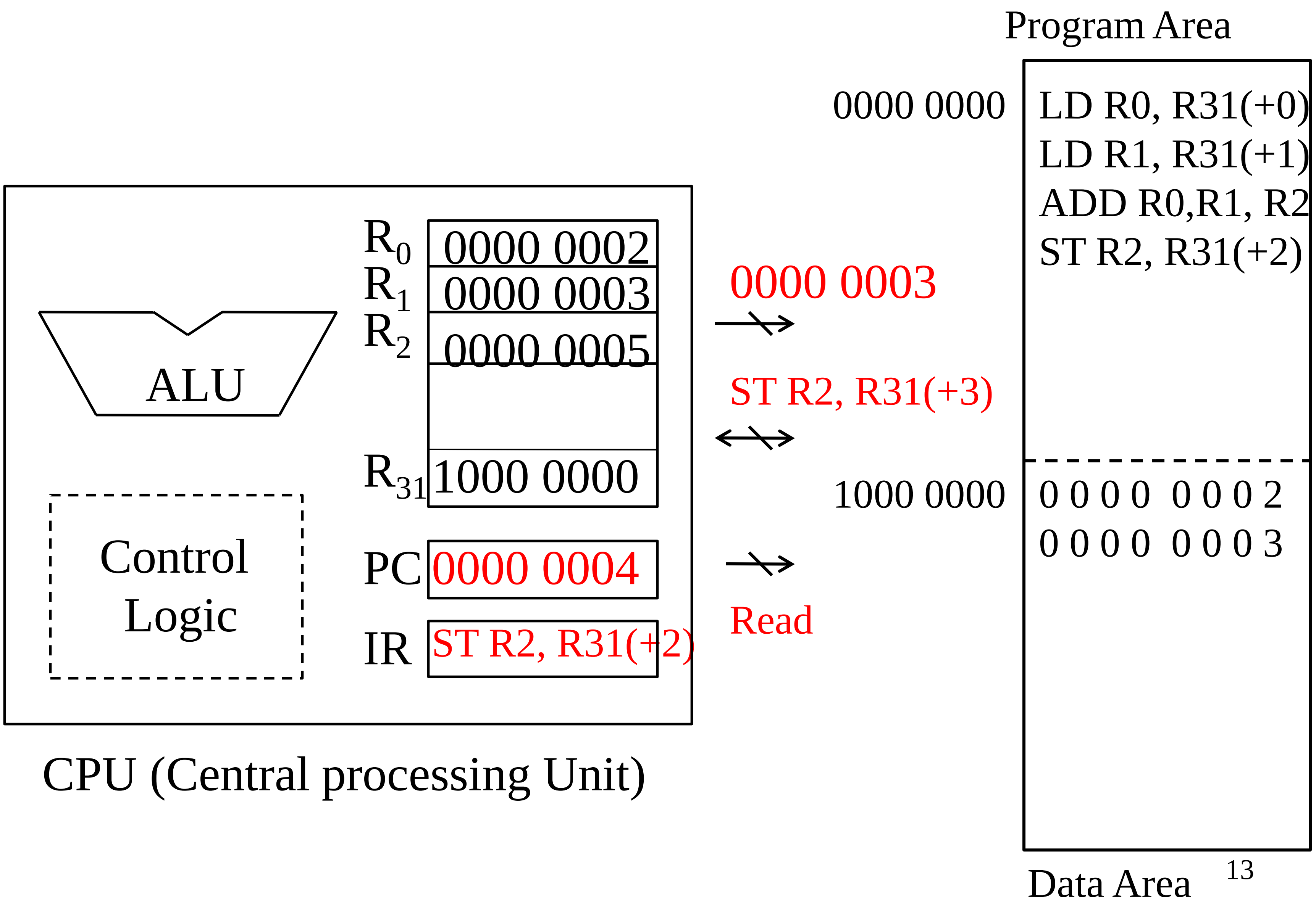
Decode and Execute 3rd Instruction

- ALU (CPU internal) operation

  $R2 \leftarrow R0 + R1$

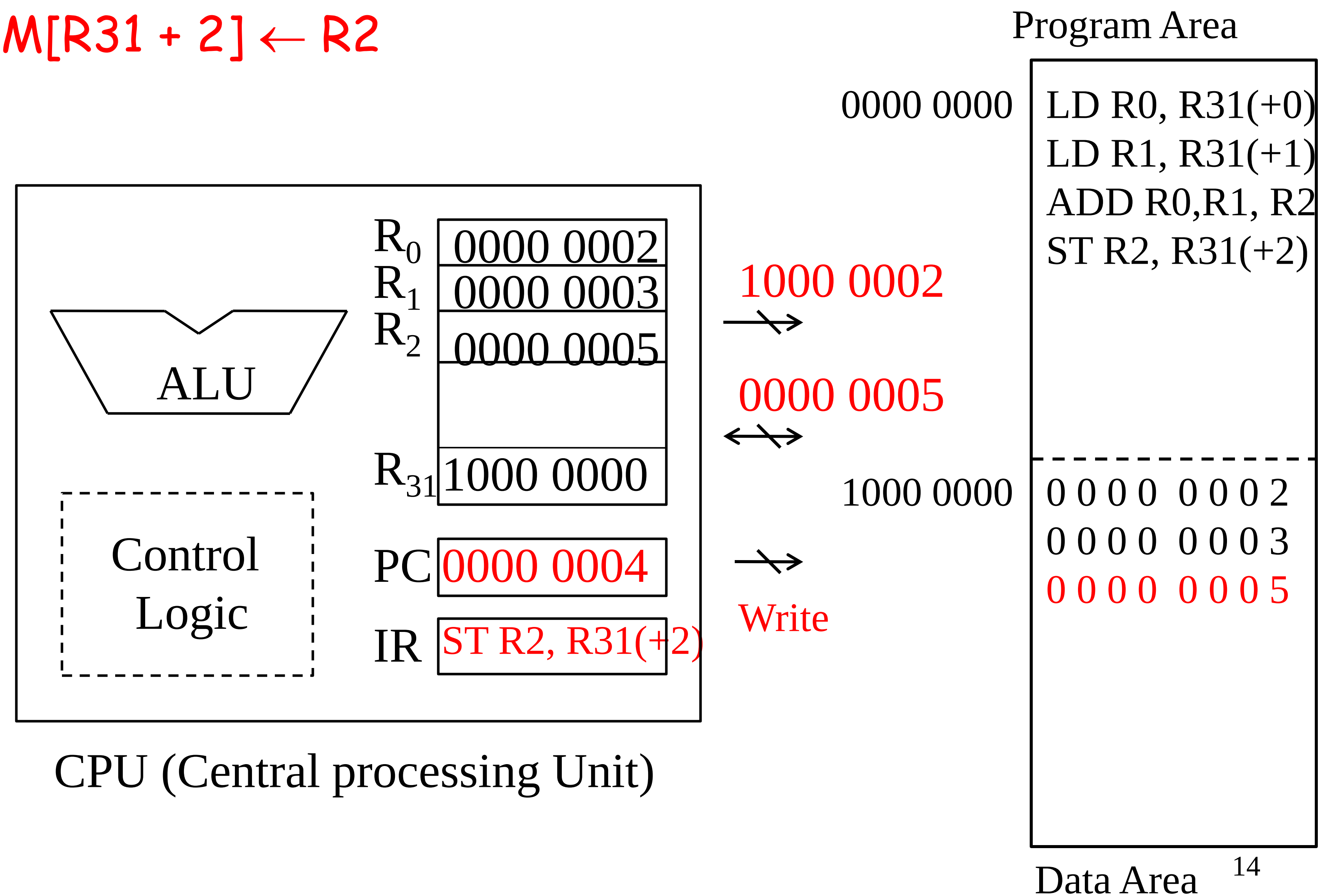


Fetch of 4th Instruction



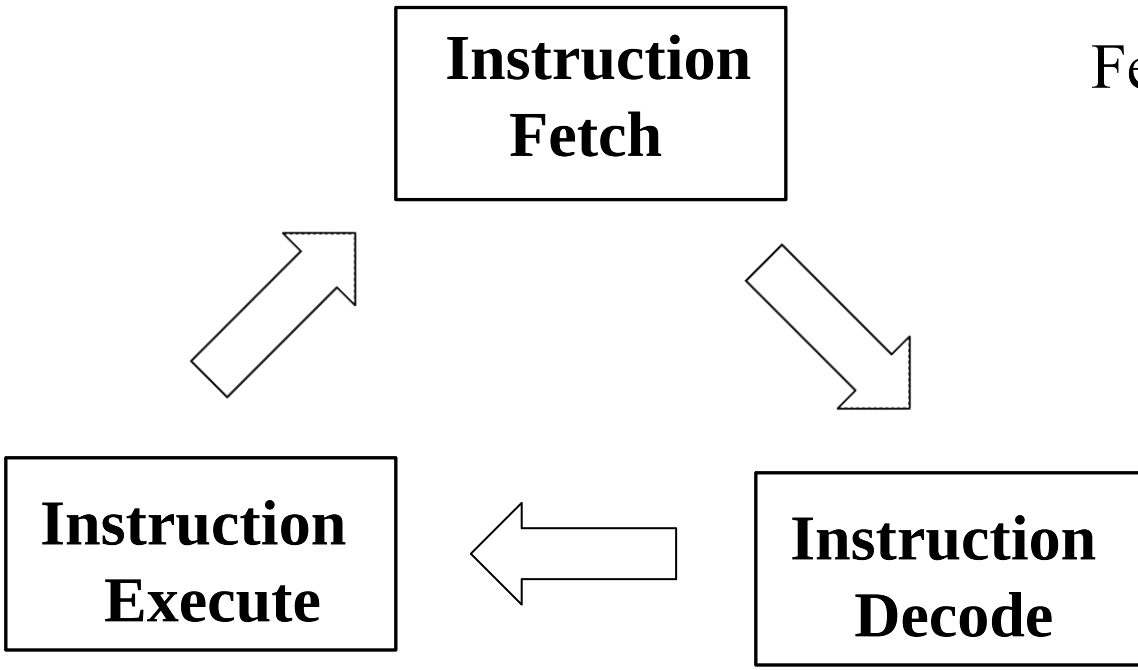
Decode and Execute 4th Instruction

$M[R31 + 2] \leftarrow R2$



Machine Cycle

- What is CPU? What is computer?

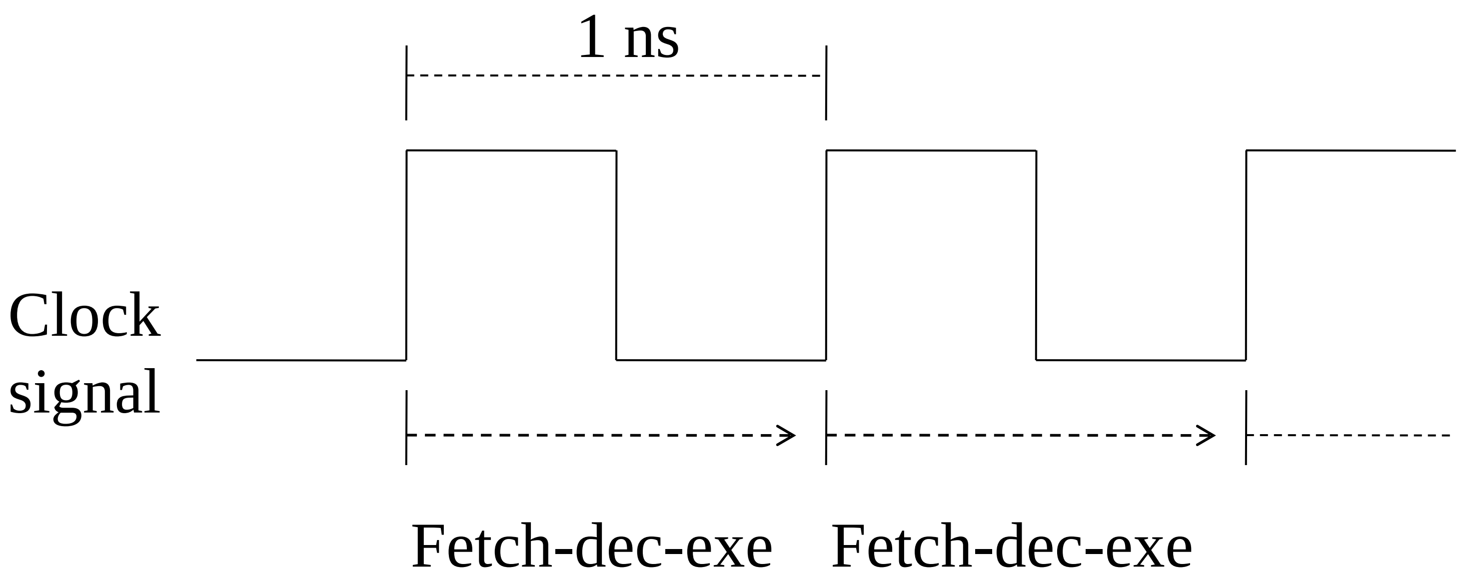


Fetch: IR $\leftarrow$ M[PC]

PC $\leftarrow$ PC+1

Time behavior

- Imagine 1 GHz CPU
  - Use 1 GHz clock
  - Clock period of 1 ns - how long is 1 ns?



ISA (Instruction Set Architecture)

Processors' external interface (what programmers must know)

Final Piece of Machine Called Computer

- Hardware components
  - CPU, memory, I/O devices
  - ALU, registers, control logic in CPU
    - Digital logic design, abstraction
  - Program and data in memory
  - Notion of address (for memory locations, I/O devices)
- Operation
  - Fetch-decode-execute cycle, timing
- What is missing?
  - ISA (Instruction Set Architecture)
    - Kind of instructions needed to be a "computer"

Need Jump Instructions

- AND, OR, NOT (Boolean algebra)
  - CPU, memory, ALU (사칙연산, 논리연산)
- IF: jump (essential for problem solving, programming)

  IF (고객이 노인) 입장료 = 정가 * 0.7

  - Conditional jump instruction

```
SUB  R1, R9, #65          //  R1 = age - 65
JUMP-NEG  R1, #1          // if negative, PC ← PC + 1
MULT  R3, R3, #0.7        // if negative, skip (no discount)
     ----
```

  - Six types of jump instructions: $=, \neq, >, <, \leq, \geq$

Instruction Set (Architecture)

- ALU instructions
  - add, sub, mult, div, and, or, not // ADD R1, R2, R3
- Data transfer instructions (for external memory, I/O)
  - load, store // LD R1, R31(#1)
- Jump instructions
  - jump if $=, \neq, >, <, \leq, \geq$

- With these, we have been computing for 70 years!
- Power of AND, OR, NOT, IF by G. Boole
  - "The Laws of Thought" versus machine called computer

Machine and Programming

- Machine called computer
  - Function determined by program
  - Service provided by CPU
    - A few tens ~ a few hundreds of instructions
      - † Use them for problem solving (programming)
- What is programming?
  - Telling computer what to do
  - Programming with machine instructions
    - Set of instructions define machine language

Assembly vs. Binary Language (참고자료)

- ALU instructions: 32-bit long (opcode, operands)

ADD R1, R2, R3

0000 1000	00001	00010	00011	
Opcode(8)	Reg(5)	Reg(5)	Reg(5)	unused(9)

OR R2, R4, R6

0000 1100	00010	00100	00110	

- The two are identical – both called machine language
  - Simple 1:1 translation
  - Assembly language: mnemonic

Assembly vs. Binary Language (참고자료)

- Jump instructions: 32-bit long

JUMP-NZ R1, 8

0100 0000	00001	000 0000 0000 00001000
Opcode(8)	Reg(5)	Jump distance(19)

JUMP-POS R2, 4

0110 0000	00010	000 0000 0000 0000 0100

- What is instruction decoding?

Assembly vs. Binary Language (참고자료)

- Load and store instructions: 32-bit long

LD R1, R31(2)

0000 0010	00001	11111	00 0000 0000 0010
Opcode(8)	Reg(5)	Reg(5)	Constant(14)

ST R2, R31(4)

0000 0011	00010	11111	00 0000 0000 0100

- Why not use absolute memory address?

Machine Called Computer

- Function determined by program
- Doing useful work with computer require:
  - Programming, software design/development
    - The term problem-solving

Programmer

Machine-level language

ISA (Pentium, PowerPC)

Machine (CPU)

Engineering = Building Abstractions

- ❑ Programmer
  - Use machine instructions for programming
    - "Interface" (사용법)
  - Not know computer design/organization/operation
    - "Implementation" (설계/구조/동작)
- ❑ Computer (CPU) 를 포함한 모든 공학 도구/물건
  - Implementation 몰라도 interface 알면 사용 가능
    - † Fundamental concept of abstraction
- ❑ Complex engineering product (e.g., 컴퓨터, 자동차, 건물)
  - 작은 부품들 사서 복잡한 모듈 만듬, 모듈들로 더 복잡한 ...
    - † Recursive abstraction building

Processor (Machine Called Computer)

- Why do you buy it? For what service?
- What kind of interface does it provide?
- What kind of abstraction does it provide?
  - ISA
- What is processor?
  - What implements ISA
- Does it look intelligent?
  - Once the software for solving differential equation is developed, then the problem is solved!
  - Reliable, very fast

Engineering Design (and the term “Architecture”)

- Marketing and requirements analysis
  - New (or existing) product; can we sell it?
- Design and implementation
  - External interface
    - How the user will use the product
  - Internal implementation
- Testing and release
- Continual enhancement

† Architecture (major interface), architect, abstraction

What is Computer Science?

- Study of problem-solving with computational devices
- What kind of problem did we solve?
  - How to build computer (i.e., machine that compute)

Machine-level language

Programmer

Machine (CPU)

ISA (Pentium, PowerPC)

† Architecture (major interface), architect, abstraction

Stored Program Concept

- Old term: von Neumann architecture
  - Fetch-decode-execute

Modern Digital Computer

- Gradual evolutions to meet human computational need
  - Capabilities, design techniques, supporting technology
- ENIAC (1943-1946)
  - First fully-electronic, general-purpose computer
  - U. Penn., Eckert, Mauchly
  - Program not in memory, vacuum tube
- What was a brilliant idea?
  - Stored program concept in 1945
  - Natural consequence: fetch-decode-execute
    - von Neumann architecture/bottleneck
    - C. Babbage's work in early 19C

ENIAC (1943-1946)

Image of ENIAC:

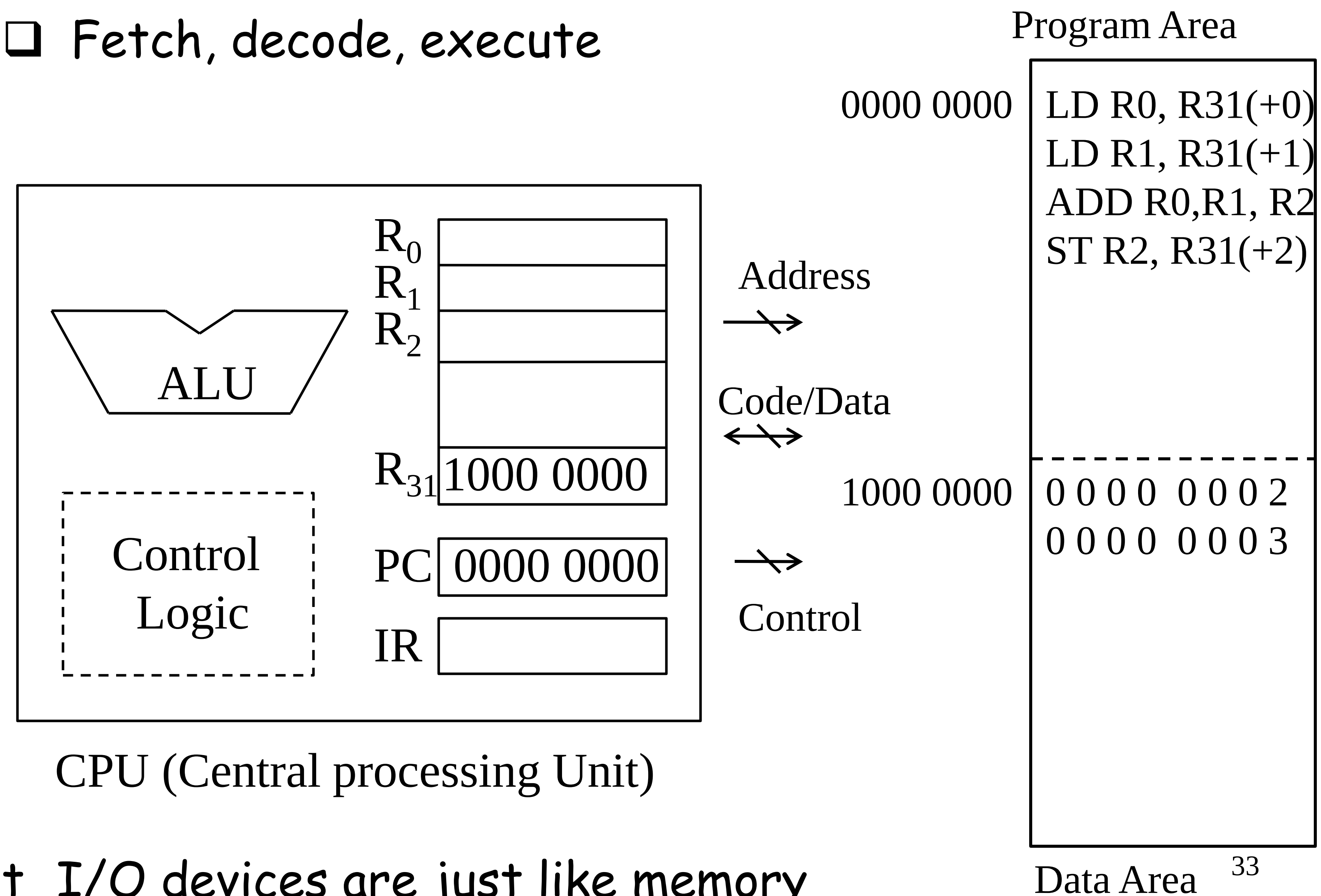
http://en.wikipedia.org/wiki/File:Classic_shot_of_the_ENIAC.jpg

Image of ENIAC:

http://en.wikipedia.org/wiki/File:Eniac.jpg

Stored Program Concept

- Fetch, decode, execute



- I/O devices are just like memory

Modern Digital Computer

- Completed by stored program concept in 1945
  - First stored program computers
    - UNIVAC I (1951), EDVAC (1952)
    - Earlier, smaller-scale British/US computers
- Next 60 years of evolution for performance
- Search continues
  - Non-von Neumann architectures
  - Alternate forms of computing
    - Biological, optical, quantum
  - Possibly, new definition of "computing"

UNIVAC I (1947-1951)

Image of UNIVAC I:

http://en.wikipedia.org/wiki/File:UNIVAC-I-BRL61-0977.jpg

Image of UNIVAC I:

http://en.wikipedia.org/wiki/File:Museum_of_Science,_Boston,_MA_-_IMG_3163.JPG

EDVAC (1945-1952)

Image of EDVAC:

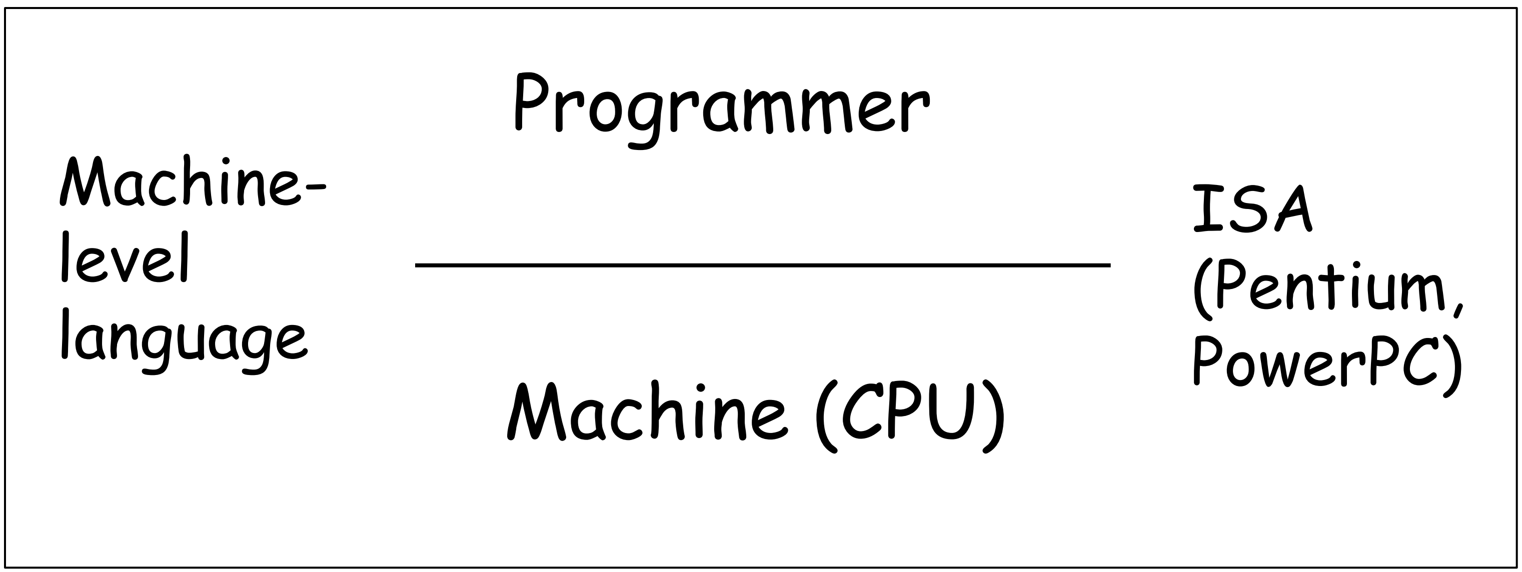
http://en.wikipedia.org/wiki/File:Edvac.jpg

Machine, Software, Internet

(not separate entities but combined whole)

Programming

- Telling computer what to do
- Machine define a (very low-level) language
  - Productive?



Program to add two numbers

```
1000    LOAD  R1, (2000)    //  load from address 2000 to R1
1004    LOAD  R2, (2004)    //  load from address 2004 to R2
1008    ADD  R3, R1, R2     //  add
100C    STORE  R3, (2008)   //  store result to address 2008
1010    HALT
        …
2000    25                  //  first operand
2004    31                  //  second operand
2008    -                   //  sum of two operands
```

C program:

```
int  a, b, c;
a = 25;
b = 31;
c = a + b;
```

Two Major Interfaces in Computer

Developers

High-level language — C, C++, Java

Compiler

(executable) Machine-level language — ISA (Pentium, PowerPC)

Machine (CPU)

- Computer language vs. natural language?
- Abstractions supported by ISA and HLL adequate? (skip)

Two Major Interfaces in Computer

- Two major interfaces
  - High-level language
  - Machine (or assembly) language
- Two major products
  - Processor
  - Compiler
- What kind of service (or abstraction) do they provide?
  - † The term "abstraction" in engineering
- If you must choose one, what will be your choice?
  - Why do we program in high-level language?

Programming Paradigms/Languages
(참고자료)

Procedural:

- Fortran, 1957 and after
- Algol, 1958
- Cobol, 1960
- Basic, 1964
- Pascal, 1970
- C, 1973
- Ada, 1983

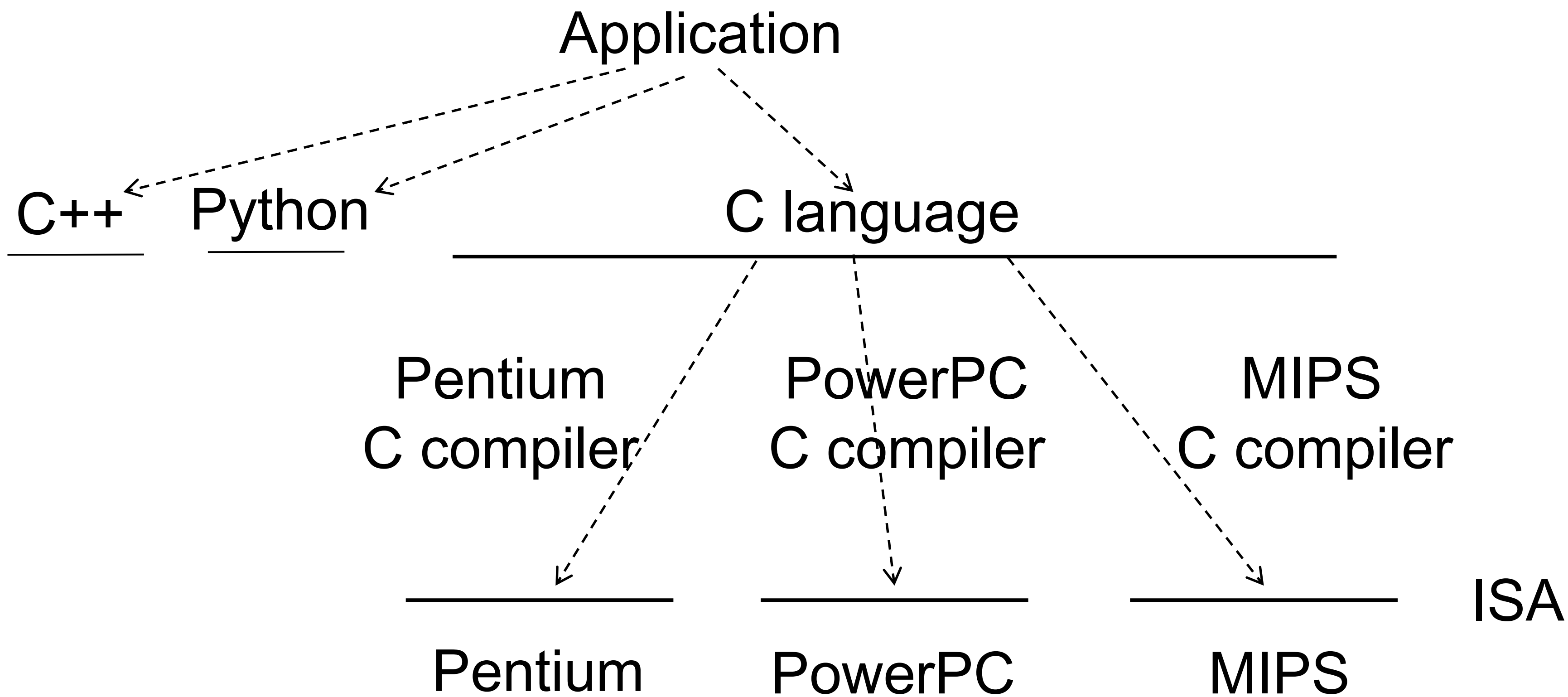
Object-oriented:

- Simula, 1967
- Smalltalk, 1980
- C++, 1985
- Perl, 1987
- Python, 1990
- Visual C++, 1993
- PHP, 1994
- Java, 1995
- Ruby, 1995
- C#, 2002

Functional: Lisp (1958)

Logic: Prolog (1972)

CPU Dependency



- ❑ You buy compiled code (e.g., Word for Pentium)
- ❑ When upgrading your PC, you choose Pentium (독점성)
  - Similar dependency exist for OS also

What is Computer Science?

- Study of <u>problem-solving</u> with <u>computational devices</u>
- What kind of problems did we solve?
  - How can we build a machine that computes?
  - How can we boost productivity in programming?

Million Lines of Source Code

Developers

Many design steps (manual) to fill semantic gap

High-level language

C, C++, Java

Compiler

(executable) Machine-level language

ISA (Pentium, PowerPC)

Machine (CPU)

Software Complexity
(data from Wikipedia)

- Operating System (OS)
  - 1 billion source lines of code (SLOC) in C++
  - Debian 2.2 (55M): 14,005 man-years, 1.9 billion US$
- How do we go about this?

Year	OS	SLOC (Million)
1993	Windows NT 3.1	4-5
1994	NT 3.5	7-8
1996	NT 4.0	11-12
2000	2000	> 29
2001	XP	45
2003	Server 2003	50

Year	OS	SLOC (Million)
2000	Debian 2.2	55-59
2002	3.0	104
2005	3.1	215
2007	4.0	283
2009	5.0	324
2005	Mac OX X 10.4	86

What is Computer Science?

- Given Pentium/C, what kinds of problems did we solve?
  - How to kill: solve differential equations
  - How to make my computer easier to use (OS)
  - How to manage the information on things (database)
  - How to connect all computers in the world (Internet)
    - Given Internet, how to share information (web)
  - Given the web, how to find what I want (search engine)
  - Given web, how to sell my products (e-commerce)
  - How to make documentation/publishing easier (Word)
  - Yet to solve: big data challenge
    - Bioinformatics, SNS data

Computer Science and Engineering

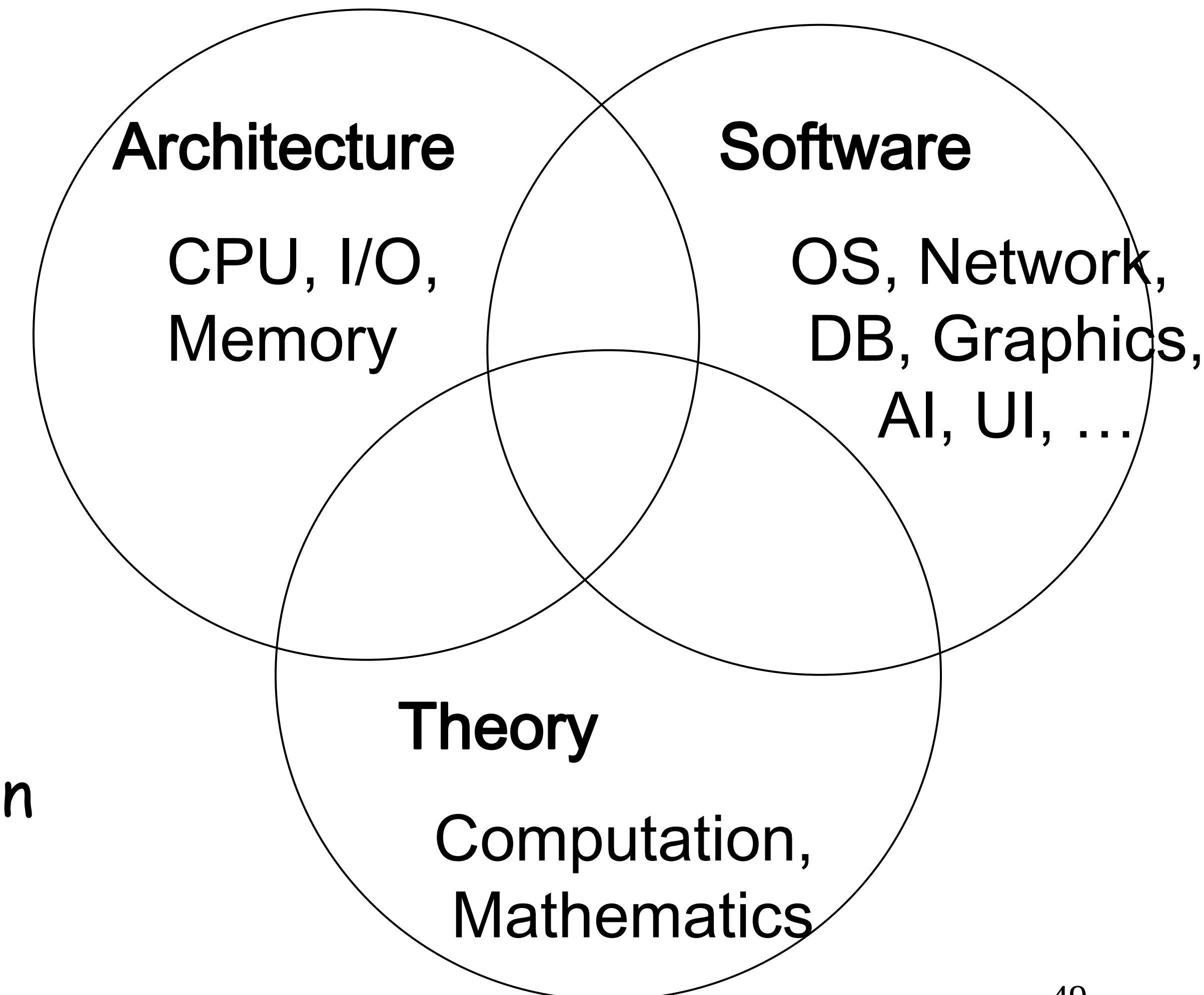
- Science vs. engineering
  - Science pursue a major new piece of knowledge
  - Engineering is about tools
    - Accumulation of knowledge facilitate engineering
- Recognition of problems, establish mathematical approaches
- Programming is about tools, processor is a tool
  - Tool development
    - Smaller-scale problem-solving by many engineers

† CS, CSE, CE

Computer Science and Engineering

- Core IT

- IT convergence
  - Management
  - Finance
  - Law
  - Automotive
  - Education
  - Transportation
  - Silver, …



IT Convergence

- ❑ 인간의 지식과 기술이 software 형태로 집약됨(국가경쟁력)
- ❑ Not by CSE major but by all elites
  - How can we build software infrastructure?

† SW 비전공자 양성 과정 (현재 준비 중임; 잠정적 자료임)

- 재학 중 본인의 전공과목과 함께 SW 기초교육 받음
- 신청자 중 선발
- 2-4 학년 동안 학기당 2과목씩 총 12 과목 이수
- 방학 중에는 SW 현장교육과 인턴 기회
- 통섭형 인재

IT Gold Rush (in USA)

IT Gold Rush in USA

- 1950 through 1970: innovation and transition
  - Transistorized computers, start using IC
  - Many big companies jump into computer ventures
    - IBM System/360 in 1965
  - Software technology
    - OS (time sharing, virtual memory, file system, …)
    - High-level programming languages, applications
  - Computers penetrate into industry
    - Minicomputers in mid 1960s
  - ISV (Independent software vendor): 2,800 in 1970
  - Service bureaus ("cloud" today)

IT Gold Rush in USA

- 1970s and 1980s: extraordinary evolution and growth
  - Processor, memory: semiconductor VLSI technology
    - Smaller/faster, exponential growth (Moore's law)
  - UNIX and C language (1969/1973)
    - Open/free OS source, renaissance of CPU design
  - Full bloom of minicomputers, relational database
  - Personal computer revolution (since 1975)
    - Whole new "shrink-wrapped software" business
    - Microsoft, Apple, Lotus, …
  - "Silicon valley"; computer networks; America Online
  - Computer/software penetrate into all vertical markets
- † BY 1990, USA far ahead of Europe and Asia

IT Gold Rush: Web, Internet

- Success of Internet: one and the only network
  - TCP and IP standard protocol of ARPAnet in 1983
  - Web: killer application [Tim Berners-Lee, 1989-1991]
  - Graphic browser by Andreessen/Netscape (1993/1994)
  - U.S. transition for commercial use (1991-1995)
- Internet, web, PC explosion in 1990s
  - Electronic commerce, information revolution
  - New business models
    - Yahoo,Google,Twitter/Facebook,YouTube,Wikipedia
- IT bubble bust in 2000/2001
  - Smartphones in 2000s
- IT convergence: IT-driven changes in all industries

Information Revolution

- Current economic/social/technological trends
- Social perspective
  - Control of info., propagation speed, people's reaction
- Electronic commerce
  - Distribution channel of goods and service
    - Eliminate distance; must be globally competitive
    - Only one economy and only one market
  - † Computer to steam engine, e-commerce to railroad
- Routinization and new business models
  - Knowledge leading factor in production
- Part of Scientific/Technical Revolution since mid-20C
  - Industrial Revolution: series of changes over 200 years
    - Initial quick changes, then hard innovations

Classes of Computers

Two Types of Computers

- General-purpose computer (범용컴퓨터)
  - 인간이 주는 (다양한 종류의) 프로그램을 실행함
    - PC, 한양대 데이터베이스 서버
- Embedded computer (내장형컴퓨터)
  - Machines 과 결합하여 다양하고 강력한 자동형 기계 형성
    - 항공기, 우주선, 자동차, 청소기, drone, 로봇, ...
  - Many different types, so many of them
    - 프로그램은 한 가지로 고정되어 있음
  - 컴퓨터는 기계를 조종하는 머리 역할 수행
    - 컴퓨터는 작고 기계에 안에 내장되어 잘 보이지 않음

† Special-purpose computer, dedicated computer

Classes of Computer Applications

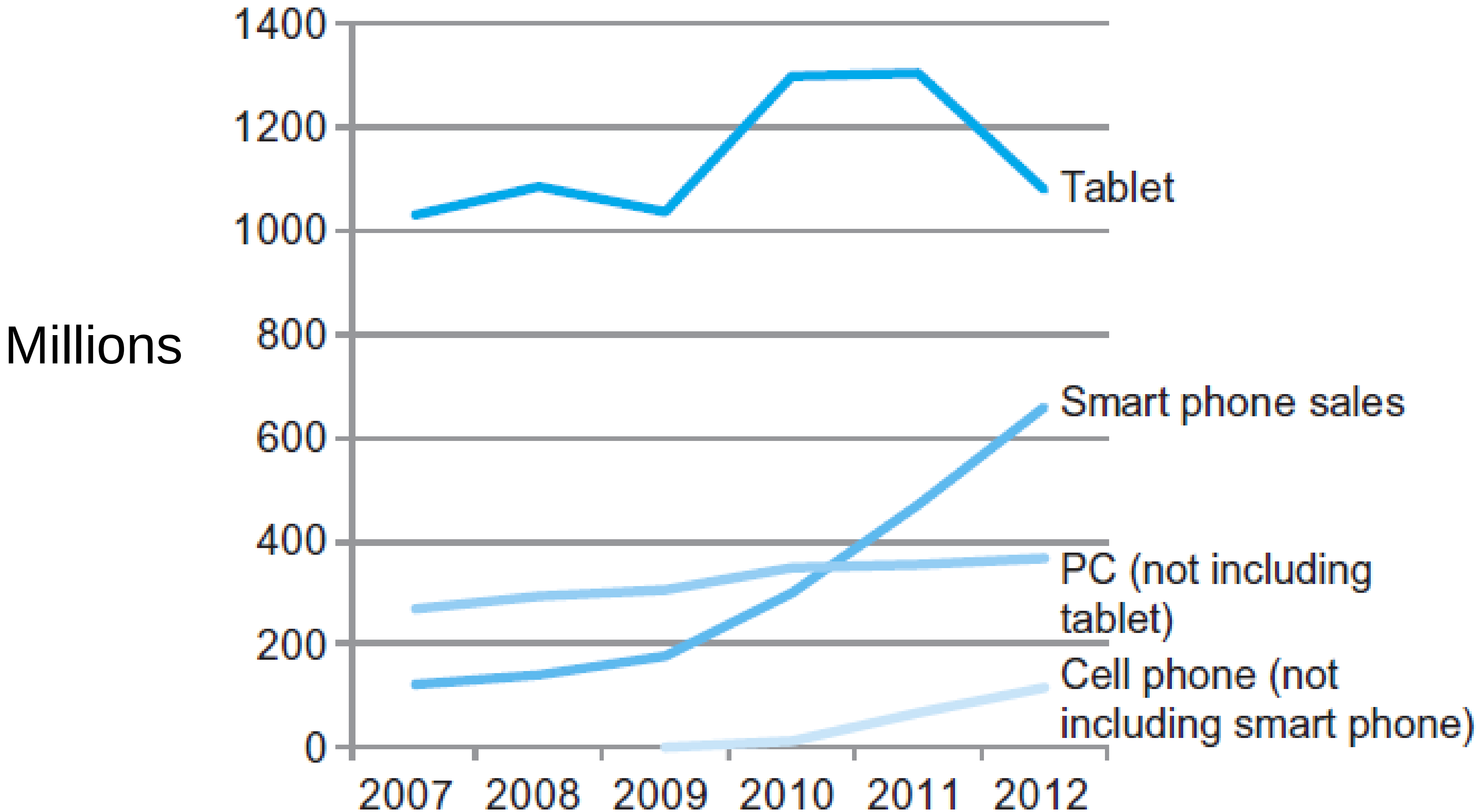
- PCs (or desktops)
  - Good performance for single user at low cost
  - Third-party software
- Servers
  - Large workload: single complex application or many small jobs (supercomputers, web servers)
  - Software from another source (database or simulation system), but customized
- Embedded computers
  - Fixed applications integrated with software, delivered as single system
  - Widest range, not seen as computers, cost and power

Evolutions Turning into Infrastructure

- Introduction of electronic computers (around 1950)
  - Evolve into business mainframes
    - Create new markets and billionaires
    - HW + OS + service (+ applications)
- Minicomputers, open Unix servers (and LAN) – 1970s
- PC (and Internet) – 1980s and 1990s
  - Shrink-wrapped software, Wintel, plug and play
- Web (or Internet) explosion in 1990s
- What's next (around 2000) – Post PC
  - Personal mobile devices and cloud
- What's next? (today's question – history repeats!)

The Post-PC Era

Source: Computer Organization and Design, Hennessy and Patterson)



The Post-PC Era

- Hardware perspective
  - Personal mobile device (PMD)
    - Smartphone or tablet (maybe glasses or wearables)
    - Battery operated, wireless connectivity to Internet
    - Download software ("apps")
    - Touch-sensitive screen or even speech input
  - Could computing (computer as utility)
    - Warehouse-scale computers (WSCs)
      - Giant data center with 100,000 servers
- Software as a Service (SaaS)
  - Software developer has a portion of application on PMD and a portion in the cloud (e.g., web search, SNS)

Cloud Computing

- H대 전산실의 경우
  - Hardware: 중대형 서버들
  - Software: OS, database, applications
  - 자체 응용 소프트웨어 유지 보수 (HY-IN)
  - 자체 인력, 예산
- IBM say: 우리한테 외주 주시오, 연 xx억만 내시오
  - HW only, HW + SW, or everything
  - 그러면 우리는 인터넷 저편 어디의 ("somewhere over the cloud") IBM 서비스를 web 을 통해 사용하게 됨
    - Will my data be safe?
- 비슷한 예: web hard, free email, ...

Cloud Computing

Computing resources delivered as service over network (Internet)

Image of cloud computing in Wikipedia: http://en.wikipedia.org/wiki/File:Cloud_computing.svg

SaaS: software as a service

PaaS: platform as a service

IaaS: infrastructure as a service

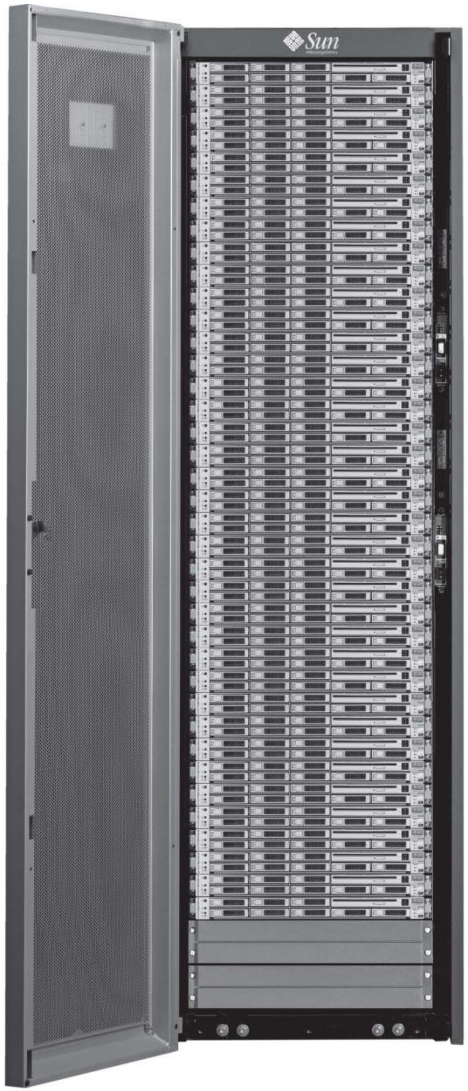
Large Data Centers

- Cloud computing
  - Computers and disks used by millions of users
  - Computer as utility
- Warehouse-scale computer
  - Space, cooling, networking, storage
- Physical design standard
  - Rack mount computer
    - 19" wide (482.6 mm)
    - 1.75" (44.45 mm) high – rack unit or unit (U)
    - Most popular: 42 U high
- Standard container filled with racks and interconnection

19-inch Rack with 42 1U servers

(Source: Computer Organization and Design, Hennessy and Patterson)

- Standard container

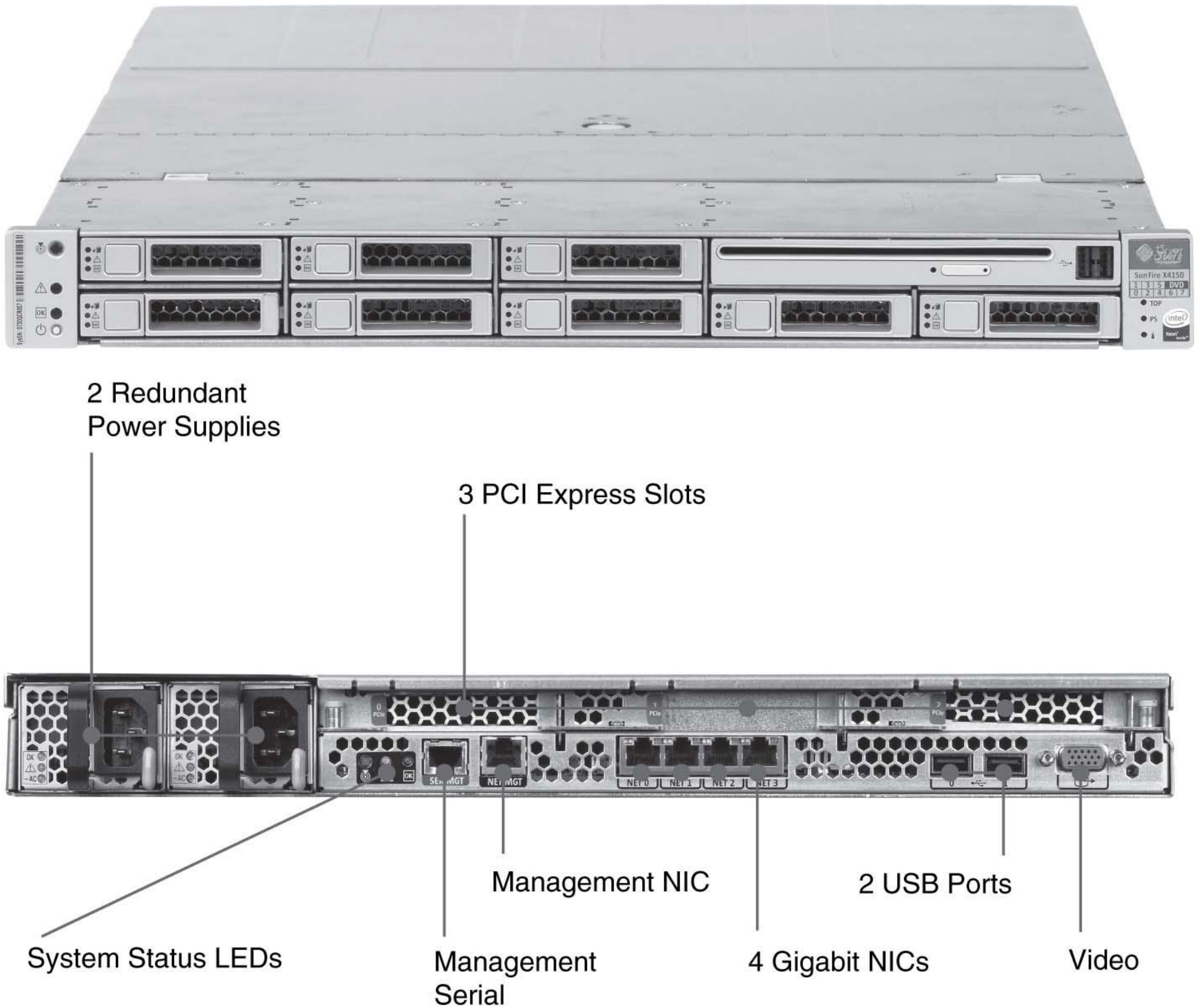


Sun Fire x4150 1U Server

(Source: Computer Organization and Design, Hennessy and Patterson)

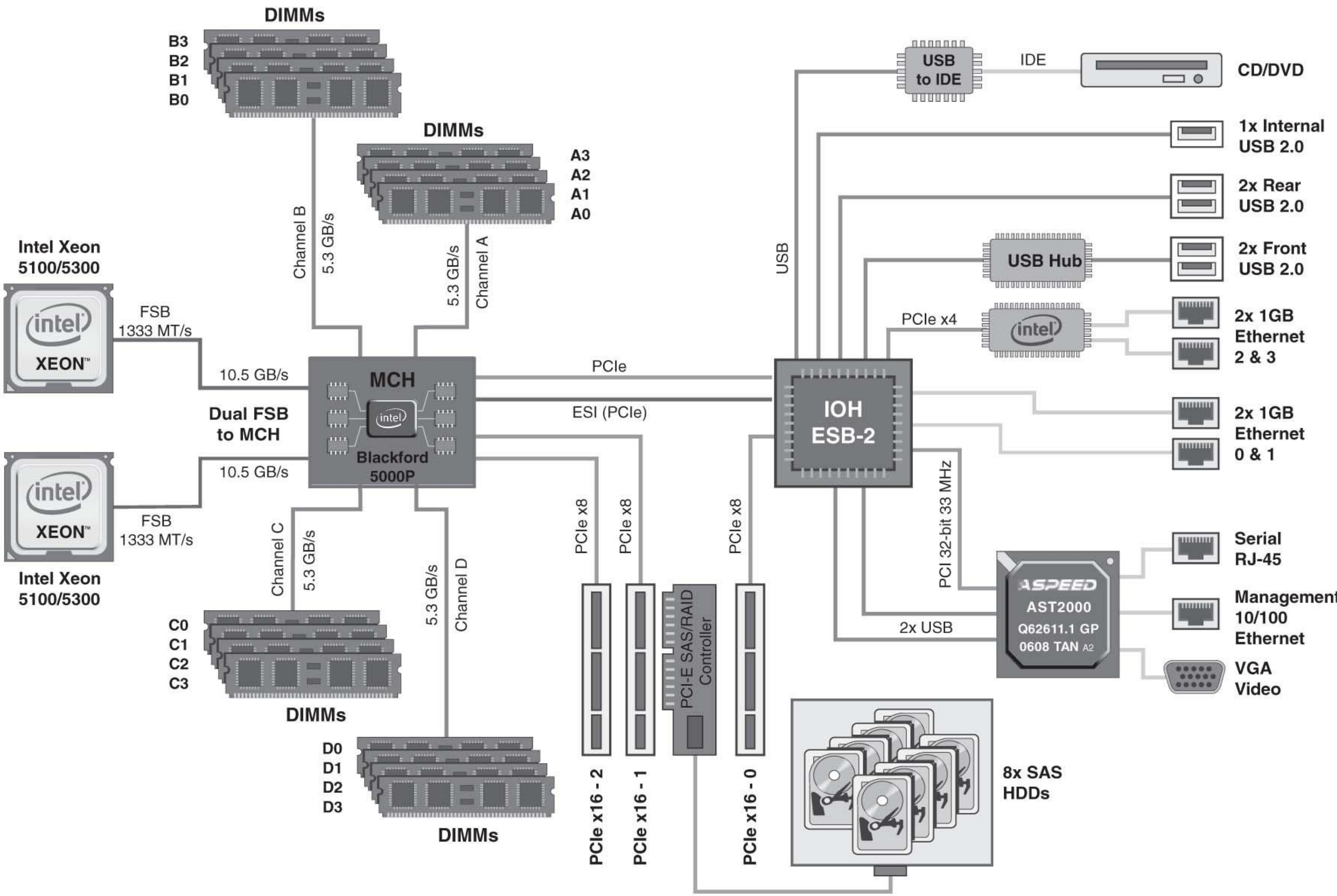
Front

Rear



Inside of Sun Fire x4150

(Source: Computer Organization and Design, Hennessy and Patterson)



Google Bigtable

Supercomputers

- Desire for highest performance possible
  - IBM, NEC, Fujitsu, Europe
  - US startups in late 1980s
    - Cray, Thinking machines, Kendal Square Research
- Financial difficulty
  - Especially due to end of cold war
- Demand for supercomputers strong and growing in commercial applications
  - Commercial aircraft and automobile design
  - Chemical engineering, weather forecasting, and so on
  - Industry must deal with cost/performance

Supercomputer

- Cray in 1980s
  - Fastest hardware with best existing technologies

Image of CRAY-2 supercomputer:
http://en.wikipedia.org/wiki/File:Cray2.jpeg
Image of CRAY T3E processor board:
http://en.wikipedia.org/wiki/File:Processor_board_cray-2_hg.jpg

Supercomputer

- 2012 fastest supercomputer: IBM Sequoia Blue Gene/Q
  - 1,572,864 processor cores, 1.6 petabytes of memory
  - 91 refrigerator-sized server racks
  - 1.6 petaFLOPS
- Why not possible with Cray style of design?
- IBM Watson

Image of IBM Blue Gene P supercomputer:
http://en.wikipedia.org/wiki/File:IBM_Blue_Gene_P_supercomputer.jpg
Image of LLNL Blue Gene L Diagram:
http://en.wikipedia.org/wiki/File:LLNL_BGL_Diagram.png

Summary

- Machine called computer
  - Basic computer organization
    - Components and interconnection
  - Operational principle
    - Fetch-decode-execute cycle
  - Service provided by CPU (or processor or computer)
    - Instruction Set Architecture
  - † Completion of modern digital computer in 1945
- Programming and problem solving
- IT Gold Rush in USA
- Classes of computers