Ada is a modern language, for modern students that solve modern problems. Ada was designed to be a language that promotes the goals of modern software engineering. It promotes modifiability, efficiency, reliability, and understandability. Ada was also designed to support the principles of modern software engineering. It promotes data abstraction, information hiding, modularity, localization, uniformity, completeness and confirmability. Ada's original design chose program readability over ease of writing. This attribute promotes code understandability, which

(continued on reverse side)
helps prevent erroneous and error-prone programs. The Ada language supports separate compilation units. This helps in program development and maintenance, which is helpful when developing large, complex software engineering projects. Given all the underlying features of Ada, it is apparent that Ada is an excellent language to use when teaching students the principles of computer science.
THE HIGHWAYS AND BYWAYS OF TEACHING ADA:
OUR BACKYARD APPROACH

FINAL REPORT

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Table of Contents

1. Background.................................................................................. 1
2. Why Use Ada................................................................. 1
3. Our Approach to Integrating Ada........................................... 2
4. Where and How to Integrate Ada........................................... 3
5. Accomplishments...................................................................... 3
6. Course Description of Classes that Incorporate Ada.............. 4
7. Conclusion................................................................................. 6

APPENDIX A................................................................................. A-1
APPENDIX B................................................................................. A-2
The Highways and Byways of Teaching Ada: Our Backyard Approach

BACKGROUND

The Illinois Institute of Technology is a private, medium-sized, coeducational university, which offers undergraduate and graduate programs through the Institute of Design and six schools and colleges: the College of Engineering and Sciences; the College of Liberal Arts; the College of Architecture; the School of Business; the College of Law and the Graduate School. The 120-acre main campus is located about three miles south of Chicago's Loop. The Computer Science Department is part of the College of Engineering and Sciences which offers Bachelor of Science, Bachelor of Arts, Masters of Science, Masters of Science for Teachers, and Doctor of Philosophy degrees. The curriculum is software centered, which is attractive to all types of majors. Our platform of choice is the IBM PC. This makes our program more interesting to students who have majors other than computer science. This accounts for our large number of students, with majors other than computer science, who enroll in our courses. IIT has an unique situation in that we offer students an education through IITV (Interactive Instructional Television Network). IITV is a live, talk-back television system that enables participating companies to offer IIT's educational programs to their employees at their places of business. The network links classroom-studios on campus with receiving classrooms at industrial and business locations so that employee-students can join IIT day and evening classes without traveling to campus.

WHY USE ADA

Ada is a modern language, for modern students that solve modern problems. Ada was designed to be a language that promotes the goals of modern software engineering. It promotes
modifiability, efficiency, reliability, and understandability. Ada was also designed to support the principles of modern software engineering. It promotes data abstraction, information hiding, modularity, localization, uniformity, completeness and confirmability. Ada's original design chose program readability over ease of writing. This attribute promotes code understandability, which helps prevent erroneous and error-prone programs. The Ada language supports separate compilation units. This helps in program development and maintenance, which is helpful when developing large, complex software engineering projects. Given all the underlying features of Ada, it is apparent that Ada is an excellent language to use when teaching students the principles of computer science.

OUR APPROACH TO INTEGRATING ADA

When we were first contemplating integrating Ada into our curriculum, we asked ourselves the question, "Why is Ada not already integrated?". We came to the conclusion that one, the students and faculty had very little to no exposure or awareness of Ada. Two, the DoD and DoD related industries are very limited in our area. Even though Ada is not just limited to the DoD, our students would have little interest in learning Ada, if they could not apply it. Three, Ada is very rich in its syntax, but our curriculum in the past has favored simpler languages like C, Pascal, Lisp/Scheme which are thought to be "easier to learn". Four; A large population of our international students end up returning to their native countries. Most of these countries have little or no use for Ada, which makes learning Ada unattractive. We consider this a "backyard approach". There is no real reason for us to teach Ada, except we realize the capabilities and powerful features that Ada possesses. Because we are not in the "mainstream" Ada community,
the acceptance of this becomes difficult. We are presented with the questions "Where do we integrate Ada into our curriculum?" and "How can this be done given our current curriculum?".

WHERE AND HOW TO INTEGRATE ADA

At first we thought of integrating Ada in our entry level courses. This seems to work well for other Universities, but at IIT we felt that to incorporate the more advanced and best features that Ada has to offer, we would need to integrate Ada at higher level. We based this on the fact that most first year students are unfamiliar with the rigors of software development, and would therefore under utilize its features and richness. Our curriculum is developed in small increments due to the accrediting concerns, so a major change would set us back. Our second choice was to develop a new sequence of software engineering courses around Ada. This was a better idea, but our undergraduate curriculum is full and adding a new sequence might not attract the interest we would need to maintain the courses. This idea also moves away from our objective of integrating Ada. This idea would isolate Ada rather than integrating it. We finally came to the conclusion that the best way for IIT to integrate Ada was to put it into our existing, and popular (i.e. required) mainstream upper-division courses. We based this decision with the following things in mind. This implementation does not require a "special audience". Our students, once at the junior or senior level, will be able to fully appreciate the richness of Ada. Also, there is a good probability that Ada would migrate into more of our curriculum.

ACCOMPLISHMENTS
Identification and Acquisition of Resources.

- Substantial resources via FTP on Internet (code, documentation, etc.).
- Ada Tutor -- shareware; copies are available and distributed to students.
- LearnAda, by AETech, which is a tutoring system and Ada compiler available to students on the IIT PCs

Additional Ada literature developed by the Teaching Assistants which has helped support course development and Ada integration.

We have hired and additional part-time instructor to teach Ada.

A 16 week Ada course available on video tape (VHS format).

COURSE DESCRIPTION OF CLASSES THAT INCORPORATE ADA

CS440: Programming Languages and Translators.

This course is a general introduction to theory and structure of languages. It covers several programming paradigms (imperative, declarative, object-oriented, functional, etc.) There has been a substantial amount of material added regarding Ada, especially:

   rich syntax
   generics
   types and type checking
   overloading
   proposed Ada9X features

The integration is included in the lecture material, homework and class exercises, examination topics and questions.

CS450: Operating Systems.

This a standard undergraduate course on operating systems. Its topics include CPU scheduling, process management, memory management, file systems, multitasking, concurrency, synchronization, security, etc. Ada is now the base language for this course. This is, of course, especially important because of the Ada tasking model. Materials developed include examples in
lecture, exercises, and examination materials. Students are strongly encouraged to submit programming assignments in Ada (although, for symmetry with our other courses, a choice of languages is provided).


This course provides an in-depth examination of the principles behind development of software intended for use in critical situations. Such situations include air-traffic control, medical applications, defense weaponry, space exploration, etc. This course also emphasizes testing, maintenance and reusability of code. Ada is the only language used in this course. Extensive programming experience in Ada, emphasizing more advanced features, is provided.

CS545: Concurrent Programming.

This is a graduate course, but it is available to undergraduates with an advisor's approval. Intensive examination and comparison of the various language testing models and there richness of support for concurrency, especially in real-time systems. Ada is the base language for this course, and extensive programming experience in Ada is provided. Ada9X issues are also explored including protected types, asynchronous transfer of control, mutual control, race conditions, etc.
CONCLUSION

We believe that our approach is fairly novel. We have not tried to duplicate efforts of other educators to develop CS1 or CS2 courses based on Ada. We have not tried to develop and "Ada Track" of courses. Instead, we are integrating Ada into the very core of our undergraduate curriculum, where Ada can be used to its fullest potential. By implementing this "backyard" approach to teaching Ada, we have been able to break the trend of other successful institutions by implementing Ada at a higher level. We have been able to take advantage of all the features that Ada has to offer, from the most basic to the most advanced. By doing this, we are able to teach modern day concepts, using a modern day language, in the comfort of our own backyard.
APPENDIX A

CS450 OPERATING SYSTEMS COURSE
SYLLABUS AND ADA LECTURE NOTES
Lecture One

Textbook

Abraham Silberschatz, James L. Peterson, Peter B. Galvin
"Operating System Concepts", Addison-Wesley, third edition, 1991, Part 1, Chapters 1, 2 and 3

References

Andrew S. Tanenbaum
"Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 1
Jean Bacon
"Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapter 1 (1.1.1, 1.1.3) and Chapter 3 (3.2 - 3.5)

Goals

To present organization of the course
To review history and evolution of the computer and operating systems
To explain the notion of the operating system
To discuss computer system structures
To discuss operating system structures

Content

Content of the course
History, Evolution, and Philosophy of Operating Systems (3 hours)
Lecture One

Organization of the Course

History and Evolution of Operating Systems

First generation (1945 - 1955)
- Vacuum Tube and Plugboards
  - First true digital computer - Charles Babbage (1792 - 1871) (unsuccesful)
  - William Howard Aiken (Harvard University), John von Neumann (Princeton University), and Konrad Zuse (Germany), all succeeded in building calculating machines using vacuum tubes
  - Large
  - Slow
  - Machine language
  - Wiring up, plugboards to control the machine's basic functions
  - Programming languages and assembly language (unknown)
  - Operating systems (unheard of)
  - Mode of operation: sign up for a block of time
  - Introduction of punched cards instead of plugboards (1950)

Second generation (1955 - 1965)
- Transistors and batch systems
  - Off-line operation
  - Batch systems
  - Control cards - modern JCL and command interpreters
  - Special program (the ancestor of today's operating system) (Fortran Monitor System - FMS and IBSYS - IBM 7094)

Third generation (1965 - 1980)
- Small-scale integrated circuits and multiprogramming
  - General purpose machines
  - Large operating systems (OS/360)
  - Multiprogramming: several jobs in memory ready for execution
  - Time-sharing: variant of multiprogramming (CTS/MIT, MULTICS - Multiplexed Information and Computer System)
  - Buffering: overlapping the I/O of a job with its own computation (I/O-bound and CPU-bound jobs)
  - Spooling (Simultaneous Peripheral Operation On Line): one program might have been executing while I/O occurred for other jobs

Fourth Generation (1980 - 1990)
- Personal Computers
  - LSI circuits
  - Workstations
  - Highly interactive computing power with excellent graphics and user-friendly software (MS-DOS, OS/2, UNIX)
  - Network and distributed operating systems

Traditional Operating Systems
- In the past most computers ran standalone and most operating systems were designed to run on a single processor
- Centralized systems: single CPU, its memory, peripherals and some terminals

Distributed Operating Systems
- Computers may be networked together, making distributed operating systems more important
- In mid 1980s:
  - Development of powerful microprocessors
  - Development of high-speed local area networks (LANs)
- Result: large number of CPUs connected by a high-speed network
- Need for radically different software:
  - Motivation
  - Goals
  - Advantages
  - Disadvantages
- Modern computers: one or more processors, main memory, clocks, terminals, disks, network interfaces and other I/O devices
- Tighty-coupled systems: processors share memory and a clock
- Loosely-coupled systems: each processor has its own memory

Real-Time Operating Systems
- Processing must be done within the defined constraints
Lecture One

Computer System Structures

- Older systems - data transfer under the CPU control - busy waiting
- multiprogramming: benefit from the overlap of CPU and I/O operations
- mechanism needed to allow synchronization of operation
- interrupt-driven data transfer
- polling
- vectored interrupt system

Main Memory

![Diagram of main memory with memory controller](image)

**Figure 1.1. Example of the interrupt-driven data transfer**

1. device controller
2. device controller
3. device controller
4. device controller
5. device controller
6. device controller

**I/O Devices**

- direct-memory-access (DMA) data transfer
  - During the transfer the disk controller is transferring data to or from memory at the same time as the processor is fetching instructions from memory and reading and writing data operands in memory. The memory controller ensures that only one of them at once is making a memory access. The disk controller may access memory between an instruction fetch and a data access which is part of the instruction execution; this is called cycle stealing. DMA slows down the rate at which the processor execute instructions.
  - High speed I/O devices
  - DMA Controller
  - Transfer of an entire block of data
directly (no intervention by the CPU).

One interrupt per block.
Lecture One

Operating System

Find a way to shield programmers from the complexity of the hardware:
To put a layer of software on top of the bare hardware to manage all parts of the system and present the user with an interface
or virtual machine that is easier to understand and program.

Keep track of many I/O requests at the same time

Device-Status Table with Request Lists

1. System call (program)
   - Put I/O request into the request list (OS)
   - Return control to one of the programs (OS)
2. Computation (program)
3. Interrupt (device - hardware)
   - Identify the source (OS)
   - Index Device-Status Table (read or modify the entry) (OS)
   - If this is completion
     - Interrupt Service Routine (OS)
     - Start new job from request list (if any) (OS)
     - Return control to one of the programs (OS)
4. Computation (user program)
Dual Mode Operation

- Single-user (programmer operated)
- Control transferred to OS
  - especially management of I/O
  - share of system resources
  - increased problems
- Increased problems
  - Error: many jobs could be adversely affected
  - All errors must be detected
    - by hardware (illegal instruction, trap,...)
- Modes of operation
  - User mode
  - Monitor (supervisor, system) mode
  - Trap or interrupt
    - User mode ➜ Monitor mode
    - After finishing its job, OS switches from
    - Monitor mode to User mode
  - Some machine instructions are privileged in Monitor mode
Lecture One

Privileged Instructions

System calls - may be used from high-level language
- all I/O instructions
- change of base and limit registers
- timer operation
  - to prevent infinite loops of never returning control to OS - fixed-rate clock and counter; OS sets the counter & clock increments it & zero generates an interrupt
- time-sharing - OS
- current time
- halt

Operating-System Services

- OS provides environment for the execution of the programs
- Service may vary
- Load program
- Run program
- Terminate (normally or abnormally)
- I/O operations
- Create file
- Delete file
- Read file
- Write file
- Communication
  - Processes on the same computer
  - Processes on the separated computers
  - By means of shared memory
  - By means of message passing
- Error protection
- Error handling
- Resource allocation
- Accounting
- Protection

System Calls

- Process control
- File manipulation
- Device manipulation
- Information maintenance
- Communications

System Programs

- File manipulation
- Status information
- File modification
- Programming - language support
- Program loading and execution
- Communications
- Applications
Lecture One

Operating System Structures

Huge systems design requires partitioning into smaller pieces carefully designed input, output, functions

① Process management

System activities

Process - program in execution

- Program is active entity
- Program is active entity (PC specifies next instruction to be executed)

System and user processes
Input: CPU data, memory, files, I/O devices
Functions: 1. Creation (deletion) of the process
2. Suspension (resumption) of the process
3. Synchronization
4. Communication
5. Deadlock handling

② Main-memory management

Main memory is a large array of words or bytes addressable and quickly accessible

Instruction-fetch cycle reads instructions
Data-fetch cycle reads or writes data

Program loaded to absolute addresses into the main memory
Memory-management schemes require hardware support
Functions: 1. Bookkeeping (what is used and by whom)
2. Who will be loaded into available space
3. Allocate and deallocate memory space

③ Secondary-memory management

Functions: 1. Free-space management
2. Storage allocation
3. Disk scheduling

④ I/O system management

Functions: 1. Buffer-caching system
2. Generic device driver interface
3. Drivers for specific hardware devices

⑤ File management

Information can be stored on a variety of physical forms: magnetic disk, magnetic tape...

Logical storage unit (file) loaded to addresses in the main memory
Physical storage unit
Functions: 1. Creation (deletion) of files and directories
2. Primitives for the manipulation of files and directories
3. Mapping files onto secondary storage
4. Backup on stable storage media

⑥ Protection system

- Memory-addressing hardware
- Controlling access to resources by means of specification
- Controlling access to resources by means of enforcement

⑦ Networking

Distributed systems do not share memory or clock
Functions: 1. Routing and connection strategies
2. Contention and security

⑧ Command-interpreter system

Part of the kernel (DOS) or running when job is initiated
Lecture Two

Textbook
Abraham Silberschatz, James L. Peterson, Peter B. Galvin
"Operating System Concepts", Addison-Wesley, third edition, 1991, Part 2, Chapter 4 (4.1, 4.2)

References
① Andrew S. Tanenbaum
"Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 2 (2.1)
② Jean Bacon
"Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapter 6

Goals
① To present the concept of the process
② To give examples of process partitioning
③ To discuss and explain process state model
④ To discuss solutions used in actual operating systems

Content
① Tasking and Processes (3 hours)
① Process Concept
② Process State Model
③ Implementation of Processes
Lecture Two

Process Concept

Notion of the process (job [batch], user program = task [time-shared])

- unit of work in a system
  - (operating) system processes
  - user processes
- active entity-program in execution (with a program counter specifying the next instruction to execute)
- program code
  - current activity
  - stack (subroutine parameters, return addresses, temporary variables, ...)
  - data section (global variables)

Defined by the resources it uses and by the location at which it is executing.

Types of processes

- system processes
- user processes
- CPU-bound processes
- I/O-bound processes
- sequential processes
  - execution of a process must progress in a sequential fashion
- concurrent processes
  - execution of a process may progress in a parallel fashion
  - reasons for allowing concurrent execution
    - resource sharing (physical and logical)
    - computation speedup (if there are multiple processing elements)
    - modularity
    - convenience
- independent processes
  - cannot affect or be affected by the other processes executing in the system
    - state is not shared
    - deterministic execution (depends solely on input)
    - reproducible execution
    - can be stopped and restarted (no ill effects)
- cooperating processes
  - can affect or be affected by the other processes executing in the system
    - state is shared
    - result is unpredictable (depends on relative execution sequence)
    - nondeterministic execution
- heavyweight processes (tasks with one thread - UNDO)
- lightweight process: (threads - basic unit of CPU utilization)
  - task is an environment in which threads execute
    - threads share:
      - code
      - address space
      - OS resources
      - less expensive context switches
    - threads own:
      - register space
      - stack

The extensive sharing makes CPU switching among peer threads and threads' creations inexpensive.

Threads can be supported by:

- Kernel - set of system calls (Mach, OS/2)
- Above the kernel - set of library calls at the user level (Andre)
Lecture Two

Figure 2.1. Examples of the processes
Figure 2.2. Process State Model

- Process states (names are arbitrary and vary from system to system)
  - submit
  - hold
  - ready (waiting to be assigned to a processor)
  - running (instructions are being executed)
  - waiting (for some event to occur: I/O completion, complete

Implementation of Processes

Data structures

- Process (Task) Control Block (record)
  - state
  - pointer
  - program counter (PC)
  - CPU registers (accumulators, index registers, stack pointers, general-purpose registers)
  - process ID
  - scheduling information
    - priority,
    - pointers to scheduling queues,
    - other scheduling parameters
  - memory-management information
    - limit registers,
    - Page Table Base Register,...
  - accounting information
    - CPU time used,
    - real time used,
    - time limits,
    - account number,
    - job or process number,...
Lecture Two

- I/O status information
  - outstanding I/O requests,
  - I/O devices allocated to this process,
  - list of open files,...
- Identity of children processes

- EXAMPLE - some of the more common fields presented in UNIX

<table>
<thead>
<tr>
<th>Process Management</th>
<th>Memory Management</th>
<th>File Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registers</td>
<td>Pointer to text segment</td>
<td>UNMASK stack</td>
</tr>
<tr>
<td>Program counter</td>
<td>Pointer to data segment</td>
<td>Root directory</td>
</tr>
<tr>
<td>Program status word</td>
<td>Pointer to bss segment</td>
<td>Working directory</td>
</tr>
<tr>
<td>Stack pointer</td>
<td>Exit status</td>
<td>File descriptors</td>
</tr>
<tr>
<td>Process state</td>
<td>Signal status</td>
<td>Effective uid</td>
</tr>
<tr>
<td>Time when process started</td>
<td>Process id</td>
<td>Effective gid</td>
</tr>
<tr>
<td>CPU time used</td>
<td>Parent process</td>
<td>System call parameters</td>
</tr>
<tr>
<td>Children's CPU time</td>
<td>Process group</td>
<td>Various flag bits</td>
</tr>
<tr>
<td>Time of next alarm</td>
<td>Real uid</td>
<td></td>
</tr>
<tr>
<td>Message queue pointers</td>
<td>Effective gid</td>
<td></td>
</tr>
<tr>
<td>Pending signal bits</td>
<td>Real gid</td>
<td></td>
</tr>
<tr>
<td>Process id</td>
<td>Effective gid</td>
<td></td>
</tr>
<tr>
<td>Various flag bits</td>
<td>Bit maps for signals</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- EXAMPLE - high-level language (Ada) description of the process descriptor structure

```ada
  type STATE is (SUBMIT, HOLD, READY, RUNNING, WAITING, COMPLETE);
  type DURATION is new REAL;
  type ADDRESS is access LONG_INTEGER;
  type PCB is record
     -- process management
     PROCESS_ID: INTEGER;
     PROCESS_STATE: STATE;
     PC: LONG_INTEGER;
     ACC: LONG_INTEGER;
     -- and other registers
     SP: ADDRESS;
     MESS_QUEUE: ADDRESS;
     CPU_TIME: DURATION;
     -- etc
     -- memory management
     TEXT_SEG: ADDRESS;
     DATA_SEG: ADDRESS;
     -- etc
     -- file management
     ROOT_DIR: STRING(1..256);
     WORK_DIR: STRING(1..256);
     FD: ADDRESS;
     -- etc
end record;
```

- The procedure of saving the state of a process and setting up the state of another is called context switching. The instructions that are executed in performing these operations and the frequency at which context switching happens are an overhead at the lowest level of a system.

Functions
- The creation and deletion of processes
  - process creation
    - via submit OS creates new processes for a job
    - via create_process system call (dynamically during the execution of process) (UNIX: fork)
      - creating processes: parent
      - created processes: children (UNIX: copy of the address space of the parent)
        - children may create their children
        - resources: inherited from parent or directly from OS
        - overloading: parent concurrently with children or parent waits until all children terminate
  - process termination
    - via terminate_process system call (after the last statement)
      - return data to parent process
      - ask OS to delete process
```
Lecture Two

via terminate_process system call (aborted from another process: usually parent or OS)

5 reasons:
- exceeded usage of resources
- task assigned to the child is no longer required
- parent is terminated (cascading termination initiated by the OS (usually children cannot exist after parent finishes))
- needed information
- ID of the children processes
- state of the children processes

- The suspension and resumption of processes
- The provision of mechanisms for process synchronization
- The provision of mechanisms for process communication
- The provision of mechanisms for deadlock handling
Lecture Three

Textbook

Abraham Silberschatz, James L. Peterson, Peter B. Galvin

References

① Andrew S. Tanenbaum
   "Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 2 (2.2.1 - 2.2.5)
② Joan Baez
   "Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapters 7, 9
③ Nnam Gohami

Goals

① To show high-level language support to the concept of the process
② To state the problems of the coordination and synchronization of concurrent activities
③ To analyze some of the programming solutions to the critical-section problem
④ To discuss hardware support for synchronization

Content

① Tasking and Processes (1 hour)
   ① Language System Support for Concurrency
② Process Coordination and Synchronization (2 hours)
   ① The Critical-Section Problem
   ② Synchronization Hardware
   ③ Semaphores
Language System Support for Concurrency

- Concurrent systems built from sequential programs with system calls
  "Each unit of the concurrent system may be a single sequential process and the operating system may provide system calls to allow interaction with other processes in addition to system calls for requesting operating system service."  *A major problem with the approach is portability of the concurrent system. The processes have made use of an operating system interface (a number of system calls) that has been provided to allow interactions between processes. If the system is to be able to run on any other operating system it is necessary for the same interface to be present. Syntactic differences can be allowed for when the code is ported, but semantic differences between operating systems are likely to occur in this area."  Jean Bacon, "Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, p. 166

- Coroutines (Modula-2, BCPL)
  Independent subprograms within a single program:
  * shared data
  * private data (own stack)
  * instructions to create and delete a coroutine
  * instruction to suspend coroutine execution temporarily but retain its state
  * instruction to pass control explicitly from the suspending coroutine to another
  * instruction to return control to the caller
  * coroutine activations must be scheduled at the user-level
  * single thread of control
  * no possibility for immediate response
  * transfer of control between coroutine activations involves very little overhead

- Language-level Processes (Concurrent Pascal, occam)
  Unlike coroutines, control is managed by an outside agency:
  * Operating system supports one process for one program: The processes within the program are managed internally by the language runtime system which effectively re-implements a process scheduler. The application programmer does not have to program the transfer of control between the language-level processes. Problem: if language-level process makes a system call to the OS to do I/O and becomes blocked then no other subprocess in the program can run.
  * Operating system recognizes subprocesses defined in a program. They become operating system processes (and may be called threads) and are scheduled by the operating system to run on processors concurrently.

- Ada Tasking Model
  Tasks become active just prior to the first executable statement following the declarations in an unspecified order. Task is completed after the execution of its body or if the exception is raised for which a handler has not been provided. A task terminates if its execution is completed and all its dependent tasks have terminated, or if it is waiting at a terminate alternative and all of its dependent tasks have terminated, there are no outstanding entry calls, its master has completed execution, all dependent tasks of the master have either terminated or are waiting at a terminate alternative.
  * Task specification
    task [type] identifier [is
    entry declarations
    [representation clauses]
    ] end identifier;
  * Task body
    task body identifier is
    declaration
    begin
    statements
    end identifier;
  * Entry declarations
    Rendezvous: matching accept statements
    Associated with each entry of a task is a queue where all newly arriving entry calls are inserted and accepted by the task in FIFO order.
    entry signal;
    entry set(T: in duration);
    entry read(C: out character);
    entry request(ID)(D: in out data):
    family of entries; ID is discrete type: IDFIRST .. IDLAST
    accept signal;
    accept set(T: in duration) do
    period := T;
    end set;
    accept request(ID)(D: in out data) do
    statements
    end request;
Lecture Three

- Entry calls
  - calling task blocked while waiting for the call to be accepted and for the duration of rendezvous
    - disk_request(4)(x);
    - sem_signal;
- Select statement
  - select
    - [ when condition1 -> ] alternative1
    - or
    - [ when conditionN -> ] alternativeN
  - end select;

A select alternative can have one of the following forms:
- accept_statement; [ statements ]
- delay t; [ statements ]
- terminate;

Process Coordination and Synchronization

- Potential concurrent execution of
  - operating system processes
  - user processes
- Mechanisms for orderly execution
  - process synchronization
  - process communication
- Example of the potentially concurrent program - Producer-Consumer Class of Problems
  - A producer process produces information that is consumed by a consumer process. To allow concurrent execution, buffer must be created to be filled by the producer and emptied by the consumer. Buffer may be unbounded or bounded.

<table>
<thead>
<tr>
<th>Producer</th>
<th>Buffer</th>
<th>Consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>print program</td>
<td>characters</td>
<td>printer driver</td>
</tr>
<tr>
<td>compiler</td>
<td>assembly code</td>
<td>assembler</td>
</tr>
<tr>
<td>assembler</td>
<td>object modules</td>
<td>loader</td>
</tr>
</tbody>
</table>

- Erroneous solution of the bounded-buffer producer-consumer problem

```plaintext
procedure PRODUCER_CONSUMER is
  N: constant INTEGER range 0..1 := 1000;
  I: O: INTEGER range 0..N-1 := 0;
  COUNTER: INTEGER := 0;
  -- shared variable for two tasks - mutually exclusive access is necessary!
  BUFFER: array (INTEGER range 0..N-1) of ITEM;
  -- synchronized access is necessary!

task PRODUCER;
  task body PRODUCER is
    NEXTP: ITEM;
    begin
      loop
        PRODUCE(NEXTP);
        while COUNTER = N loop exit end loop;
        -- synchronization: cannot produce items if buffer is full
        BUFFER(I) := NEXTP;
        I := (I + 1) mod N;
        COUNTER := COUNTER + 1;
        -- without mutual exclusion program is erroneous
      end loop;
    end PRODUCER;

  task CONSUMER;
  task body CONSUMER is
    NEXTC: ITEM;
```
Lecture Three

```
begin
  loop
    while COUNTER = 0 loop null; end loop;
    -- synchronization: cannot consume items if buffer is empty
    NEXTC := BUFFER(O);
    O := (O + 1) mod N;
    COUNTER := COUNTER - 1;
    -- without mutual exclusion program is erroneous
    CONSUME(NEXTC);
  end loop;
  end CONSUMER;
end;
end PRODUCER_CONSUMER;
```

The Critical-Section Problem

A critical section is a segment of code in which the process may be changing common variables. A solution to the problem must satisfy the following requirements:

1. mutual exclusion
2. progress: "If no process is executing in its critical section and there exist some processes that wish to enter their critical sections, then only those processes that are not executing in their remainder sections can participate in the decision as to which will enter its critical section next, and this selection cannot be postponed indefinitely." A. Silberschatz, J.L. Peterson, P.B. Galvin. "Operating System Concepts", third edition, Addison-Wesley 1990, p. 134
3. bounded waiting

Two-process solutions

1. First solution (erroneous)

```
procedure ALGORITHM1 is
  TURN: INTEGER range 0..1 := 0;
  task P0;
  task body P0 is
    begin
      loop
        while TURN <> 0 loop null; end loop;
        -- critical section
        TURN := 1;
        -- remainder section
      end loop;
    end P0;
  task P1;
  task body P1 is
    begin
      loop
        while TURN <> 1 loop null; end loop;
        -- critical section
        TURN := 0;
        -- remainder section
      end loop;
    end P1;
begin
  null;
end ALGORITHM1;
```

The execution sequence which does not satisfy progress requirement:
1. TURN is initially 0
2. Task P0 enters and exists its critical section and sets TURN to 1
3. Task P0 is interrupted in its remainder section
4. Task P1 enters and exists its critical section, sets TURN to 0, enters and exists its remainder section and wishes to enter its critical section again
5. Task P1 has to wait although task P0 is in its remainder section, because TURN is 0

4
Lecture Three

○ Second solution (arrangeous)

procedure ALGORITHM3 is
  FLAG: array (INTEGER range 0..1) of BOOLEAN := (FALSE, FALSE);
  task P0;
  task body P0 is
  begin
  loop
    FLAG(0) := TRUE;
    while (FLAG(1) and TURN = 0) loop null; end loop;
    -- critical section
    FLAG(0) := FALSE;
    -- remainder section
  end loop;
  end P0;
  task P1;
  task body P1 is
  begin
  loop
    FLAG(1) := TRUE;
    while (FLAG(0) and TURN = 1) loop null; end loop;
    -- critical section
    FLAG(1) := FALSE;
    -- remainder section
  end loop;
  end P1;
begin
  null;
end ALGORITHM3;

The execution sequence which may lead to indefinite looping of tasks P0 and P1 in their respective while statements:
1. Task P0 is interrupted after assigning TRUE to FLAG(0)
2. Task P1 is interrupted after assigning TRUE to FLAG(1)
3. Both tasks may proceed now but they will endlessly loop within their while statements

○ Third solution

procedure ALGORITHM3 is
  TURN: INTEGER range 0..1 := 0;
  FLAG: array (INTEGER range 0..1) of BOOLEAN := (FALSE, FALSE);
  task P0;
  task body P0 is
  begin
  loop
    FLAG(0) := TRUE;
    TURN := 1;
    while (FLAG(1) and TURN = 1) loop null; end loop;
    -- critical section
    FLAG(0) := FALSE;
    -- remainder section
  end loop;
  end P0;
  task P1;
  task body P1 is
  begin
  loop
    FLAG(1) := TRUE;
    TURN := 0;
    while (FLAG(0) and TURN = 0) loop null; end loop;
    -- critical section
    FLAG(1) := FALSE;
    -- remainder section
  end loop;
  end P1;
Lecture Three

begin

multithreaded algorithm;

Synchronization Hardware

1. Disallow interrupts
2. Atomic execution
3. Enter and Exit
4. Swap

Semaphores

\texttt{wait(s) (or P(s)):} \quad \text{while } s > 0 \text{ loop and loop; } s := s - 1; \quad \text{(modify without busy waiting)}

\texttt{signal(s) (or V(s)):} \quad s := s + 1;

1. Synchronization

\texttt{synch := 0;}

\texttt{P_1:: \quad S_1;}

\texttt{signal(synch);}

\texttt{P_2:: \quad wait(synch);}

\texttt{S_2;}

1. Mutual exclusion

\texttt{loop}

\texttt{wait(mtx);}

\texttt{-- critical section}

\texttt{signal(mtx);}

\texttt{-- remainder section}

\texttt{end loop;}

1. Advantages

avoid busy waiting; process blocks itself \& waiting queue associated with the semaphore (policy: LIFO \& starvation)

1. Disadvantages

\textbullet \quad rely too much on programmer
\textbullet \quad deadlock
\textbullet \quad unreadable
\textbullet \quad complex
Lecture Four

Textbook

Abraham Silberschatz, James L. Peterson, Peter B. Galvin
"Operating System Concepts", Addison-Wesley, third edition, 1991, Part 2, Chapter 5 (5.5 - 5.7)

References

① Andrew S. Tanenbaum
  "Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 2 (2.2.6 - 2.2.9, 2.3)
⑥  Jean Bacon
  "Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapters 10 - 12, 14

Goals

① To analyze solutions to some of the classical problems of synchronization
⑥ To present different language constructs
⑥ To analyze some of the programming solutions to the critical-section problem
⑥ To discuss principles of IPC
⑥ To discuss main concepts of scheduling

Content

① Process Coordination and Synchronization (2 hours)
  ① Classical Problems of Synchronization
  ① Language Constructs and Interprocess Communication
⑥ Scheduling (1 hour)
  ① Concepts
Lecture Four

Classical Problems of Synchronization

The Bounded-Buffer Problem

Ada 93 solution

procedure PRODUCER_CONSUMER is

  task PRODUCER;
  task body PRODUCER is
    NEXTP: ITEM;
    begin
      loop
        PRODUCE(NEXTP);
        BUFFERING.PUT(NEXTP);
        end loop;
        end PRODUCER;

  task CONSUMER;
  task body CONSUMER is
    NEXTC: ITEM;
    begin
      loop
        BUFFERING.GET(NEXTC);
        CONSUME(NEXTC);
        end loop;
        end CONSUMER;

  task BUFFERING is
    entry PUT(X: in ITEM);
    entry GET(X: out ITEM);
    begin
      loop
        select
          when COUNTER < N =>
            accept PUT(X: in ITEM) do
              BUFFER(i) := X;
            end;
            I := (I + 1) mod N;
            COUNTER := COUNTER + 1;
          or when COUNTER > 0 =>
            accept GET(X: out ITEM) do
              X := BUFFER(O);
            end;
            O := (O + 1) mod N;
            COUNTER := COUNTER - 1;
          end select;
        end loop;
      end BUFFERING;

begin
  PRODUCER_CONSUMER;
  end;


generic
  type MESSAGE_TYPE is private;
package MESSAGE_PKG is
  type MESSAGE_ARRAY is array(POSITIVE range <>) of MESSAGE_TYPE;
protected type MAILBOX(SIZE: NATURAL) is
  function COUNT return NATURAL;
  procedure DISCARD_ALL;
  entry PUT(MESSAGE: in MESSAGE_TYPE); 
  entry GET(MESSAGE: out MESSAGE_TYPE);
Lecture Four

private
 CONTENTS: MESSAGE_ARRAY(1..SIZE);
 CURRENT_COUNT: NATURAL := 0;
 PUT_INDEX: POSITIVE := 1;
 GET_INDEX: POSITIVE := 1;
 and MAILBOX_PKG;
 package body MAILBOX_PKG is
 protected body MAILBOX is
 function COUNT return NATURAL is
 begin
 return CURRENT_COUNT;
 end COUNT:

 procedure DISCARD_ALL is
 begin
 COUNT := 1;
 PUT_INDEX := 1;
 GET_INDEX := 1;
 end DISCARD_ALL;

 entry PUT(MESSAGE: in MESSAGE_TYPE) when COUNT < SIZE is
 begin
 CONTENTS(PUT_INDEX) := MESSAGE;
 PUT_INDEX := PUT_INDEX mod SIZE + 1;
 COUNT := COUNT + 1;
 end PUT;

 entry GET(MESSAGE: out MESSAGE_TYPE) when COUNT > 0 is
 begin
 MESSAGE := CONTENTS(GET_INDEX);
 GET_INDEX := GET_INDEX mod SIZE + 1;
 COUNT := COUNT - 1;
 end GET;
 end MAILBOX;
 end MAILBOX_PKG;

 with TEXT_IO, MAILBOX_PKG;
 procedure TEST is
 type LINE is
 record
 LENGTH: NATURAL := 0;
 DATA: STRING(1..80);
 end record;
 package LINE_BUFFER_PKG is
 new MAILBOX_PKG(MESSAGE_TYPE => LINE);
 LINE_BUFFER: LINE_BUFFER_PKG.MAILBOX(SIZE => 20);

 task PRODUCER;
 task body PRODUCER is
 L: LINE;
 begin
 for I in 1..10 loop
 TEXT_IO.GET_LINE(L.DATAS, L.LENGTH);
 LINE_BUFFER.PUT(L);
 end loop
 end PRODUCER;

 task CONSUMER;
 task body CONSUMER is
 L: LINE; C: NATURAL;
 begin
 for I in 1..10 loop
 LINE_BUFFER.GET(L);
 TEXT_IO.PUT_LINE(L.DATAS(1..L.LENGTH));
 C := LINE_BUFFER.COUNT;
 if C > LINE_BUFFER/2 then
 TEXT_IO.PUT_LINE("Buffer count was " & INTEGER_IMAGE(C));
 end if;
 end loop
 end CONSUMER;
Lecture Four

begin
end with
end TEXT:

The Readers and Writers Problem

The Dining-Philosophers Problem

with TEXT_IO; use TEXT_IO;
procedure DDING is
package IO_INT is new INTEGER_IO(INTEGER); use IO_INT;
subtype ID is INTEGER range 1..5;
task type PHILosopher is
entry GET_ID(I: in ID);
end PHILosopher;
task type FORK is
entry PICK_UP;
entry PUT_DOWN;
end FORK;
F: array(ID) of FORK;
F: array(ID) of PHILosopher;
task body PHILosopher is
ME, LEFT, RIGHT: ID;
LIFE_LIMIT: constant 105_000;
TIMES_EATEN: INTEGER := 0;
begin
accept GET_ID(I: in ID) do ME := I; and GET_ID;
LEFT := ME; RIGHT := ME mod 5 + 1;
while TIMES_EATEN < LIFELIMIT loop
THINK;
F(LEFT).PICK_UP; F(RIGHT).PICK_UP;
EAT;
F(RIGHT).PUT_DOWN; F(LEFT).PUT_DOWN;
TIMES_EATEN := TIMES_EATEN + 1;
end loop;
end PHILosopher;
task body FORK is
begin
loop
accept PICK_UP; accept PUT_DOWN;
or
terminate;
end loop;
end FORK;

begin
for K in ID loop F(K).GET_ID(K); end loop;
end DDING:

The Sleeping-Hunter Problem

Language Constructs and Interprocess Communication

- Conditional Critical Regions
  - Compiler should check and enforce that
  - shared data is only accessed from within a critical region
  - critical regions are entered and left correctly by processes
  - Syntax:
    - shared as an attribute of any data type
    - a region declaration
      - region <shared data> when <condition> begin <statements> end
Lecture Four

- Monitors
  - A monitor has the structure of an abstract data object
  - Encapsulated data are shared
  - Each operation is executed under mutual exclusion
  - Process may delay itself on condition variable

Syntax:
  - monitor name is
  - entry procedures <list of procedure names visible externally>
    variable declarations and initialization of values
    external procedure declarations and bodies
    internal procedure declarations and bodies
  - end name;

![Diagram of monitor structure](image)

**Figure 4.1.** Program structure with monitors

- Process A
  - Call to monitor procedure
- Process B
  - Call to monitor procedure

![Diagram of condition synchronization](image)

**Figure 4.2.** Condition synchronization under exclusion in a monitor procedure

- monitor name is
  - entry procedures <list of procedure names visible externally>
    variable declarations and initialization of values
    external procedure declarations and bodies
    internal procedure declarations and bodies
  - end name;

- Enter: new process now have mutual exclusion.
- Can I proceed to operate on the shared data or must I block?

  - `WAIH(condition-variable-name)`
  - Release the exclusion on the monitor

- Operate on the shared data
- Exit: release mutual exclusion and return

- `0` = delay and potential delay
Who will be blocked after the SIGNAL operation?

- signalling process: signalling process will be put at the head of the monitor wait queue. Monitor data must be in a consistent state before a SIGNAL is executed.
- signalled process: transfer the signalled process from the condition variable queue on which it is waiting to the head of the queue of processes waiting to enter the monitor

- Path Expressions
- Message Passing Mechanisms
  - Asynchronous
    - Receiving from 'anyone'
    - Request and reply primitives
    - Multiple ports per process
    - Input ports, output ports and channels
    - Global ports
    - Broadcast and multicast
    - Message forwarding
  - Synchronous
    - access channel
    - Linda abstraction

Scheduling Concepts

- multiprogramming
- maximize CPU utilization
- throughput
- amount of work accomplished in a given time interval
- enter the system
- job queue (on mass storage awaiting allocation of main memory)
- enter the main memory
- ready queue
- running
- request of I/O
- device queue
Lecture Four

Figure 4.5. Benefits of the parallel execution

Select processes from various scheduling queues

- long-term scheduler (job scheduler) may not exist
  - Job queue is on the mass storage device
  - Chooses a small subset of jobs submitted and lets them into the system
  - Creates processes
  - Assigns some resources
  - Requirements: executes less frequently
  - controls the degree of multiprogramming (if stable same rate of creation and deletion)
  - good process mix (I/O-bound and CPU-bound)

- medium-term scheduler
  - Swapping
    - Partially executed queue → secondary memory
    - Requirements: improve the process mix
    - reason - change of memory requirements

- short-term scheduler (CPU scheduler)
  - CPU scheduler manages ready queue
  - When CPU scheduling takes places?
    - running state @ waiting state
      - Ex. I/O request, wait for termination of the child process
      - process is blocked @ another should be selected
    - running state @ ready state
      - Ex. interrupt (time-out,...)
      - after OS services (interrupt routine,...) finish their job @ another process (possibly the same)
      - should be selected for execution
    - waiting state @ ready state
      - Ex. completion of I/O
    - running state @ complete state
  - Process consists of a cycle of CPU execution and I/O wait
    - CPU-bound process
    - I/O-bound process

Functionality

1. Choose a process for execution from ready queue
2. Call dispatcher to do the physical assignment of the job to the processor
3. Ready queue (main memory)
4. Assigns process to a process: which, when and for how long?

Requirements:

- executes very often @ must be very fast
- statistics on CPU-burst - I/O-burst cycle may be important in selecting an algorithm
- expectations: a very large number of very short CPU-bursts

trigger - change of process state

Schemes: non-preemptive scheduling

trigger: running to waiting state
termination
overhead is smaller, simple, easy to implement, may be reasonable for dedicated systems (e.g., database systems) where master process knows how long child will run

preemptive scheduling
trigger: running to ready state (interrupt, time slice)
or waiting to ready state (completion of I/O)
circumstances may be changed and more appropriate decision made

context switch
saving the state of the old process
loading the saved state for the new process
context-switch time (% pure overhead) depends on

hardware support
memory speed
number of registers
register sets
software support
special instruction to load/store all registers

dispatcher
physically gives control to the selected process
functions
switching context
switching to user mode
jumping to the proper location to restart the program

comparison criteria
Criteria selection defined according to the relative importance of these measures

CPU utilization (% of time when CPU is busy) maximize
Throughput (number of processes per time unit) maximize

Figure 4.6. Difference between two comparison criteria

(C) turnaround time (time of completion - time of submission)
(C) waiting time (in ready queue)
(C) response time (time of first response - time of submission)
or optimize the min and max values rather than average
or optimize average measure
or minimize variance

(1) fairness (make sure each process gets its fair share of the CPU)
"Any scheduling algorithm that favors some class of jobs hurts another class of jobs."

3
Lecture Four


Evaluation

1. Analytic evaluation
   - Algorithm
   - System workload
   - Deterministic modelling - predetermined workload
   - Queueing modelling (queueing-network analysis)
     - Measure distribution of I/O and CPU bursts
     - Arrival rates
     - Service rates

2. Simulation (programming a model of the computer system)
   - Clock - variable
   - Clock value increased - system state modified to reflect the activities of the devices, the processes and the scheduler
   - Statistics of algorithm performance
   - Random number generator (for events according to the probability distributions) or trace tapes

3. Implementation
   Analyze the real situation of CPU utilization taking into account time for OS intervention
Lecture Five

Textbook

Abraham Silberschatz, James L. Peterson, Peter B. Galvin
"Operating System Concepts", Addison-Wesley, third edition, 1991, Part 2, Chapter 4 (4.4 - 4.7), Chapter 6 (6.1 - 6.2)

References

1. Andrew S. Tanenbaum
   "Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 2 (2.4), Chapter 6 (6.1 - 6.2)
2. Jean Bacon
   "Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapter 6 (6.6 - 6.8), Chapter 16 (16.1 - 16.5)

Goals

1. To analyze some of the existing scheduling algorithms
2. To present different evaluation techniques
3. To introduce the concept of deadlock

Content

1. Scheduling and Dispatch (2 hours)
   1. Scheduling Algorithms and Their Evaluation
2. Deadlocks (1 hour)
   1. System Modelling
   2. Deadlock Characterisation
Scheduling Algorithms and Their Evaluation

Algorithms
- First-Come First-Served (FCFS)
  - FIFO queue
  - incoming ready process is linked onto the tail of the ready queue
  - CPU is allocated to the process at the head of the ready queue
  - Average waiting time is long

Critique
- FCFS
- Ex. CPU-bound process and many I/O-bound processes
- Nonpreemptive

- Shortest-Job-First (SJF)
  - Criteria
    - process with smallest next CPU-burst
    - tie - FCFS
    - Provably optimal (minimum average waiting time)

![Figure 5.1. SJF - Optimal Algorithm](image)

- Problems
  - How can CPU know the length of the next CPU-burst interval?
  - batch systems
    - job scheduler
    - user should submit punched control card with process time limit ("time-limit-exceeded error")
  - prediction
    - Exponential average: \( \phi_{n+1} = (1 - \delta)\phi_n + (1 - \delta^2)\delta^t \delta_0 \)
      - recent history, \( \phi_n \) - past history
      - \( \delta = 0 \), past history prevails
      - \( \delta = 1/2 \), equally distributed
      - \( \delta = 1 \), recent history prevails
  - Expanded formula
    - \( \phi_{n+1} = (1 - \delta)\phi_n + (1 - \delta^2)\delta^t \delta_0 \)
      - \( \delta_0 \) - constant or overall system average

- Type
  - preemptive
    - CPU-burst, next process < CPU-burst, what is left of the currently executing process
    - shortest-remaining-time-limit
  - nonpreemptive

Example
- task SJF_SCHEDULER is
  - entry ADD(JOB-ID; T:DURATION);
  - entry GET(JOB; out ID);
  - return the next job to be executed and delete it
  - end SJF_SCHEDULER;

- task body SJF_SCHEDULER is
  - ID;
  - PERIOD:DURATION;
  - begin
    - loop
      - select
        - accept ADD(JOB-ID; T:DURATION) do
          - I := JOB;
          - PERIOD := T;
          - and ADD;
          - INSERT(I, PERIOD);
          - or
          - end if
        - end loop
      - return;
    - end loop
  - end body

- 2
Lecture Five

```
when not EMPTY (Q)
accept GET/JOB; end ID) do
  SMALLEST(JOB);
  and GET;
end select;
end loop;
end SIF_SCHEDULER;
```

procedure INSERT(JOB; ID; T-DURATION);
-- add job to the set; T is the next CPU-burst time
procedure SMALLEST(JOB; end ID);
-- JOB is set to the id of the job with the smallest next CPU-burst time and this job is deleted from the set; call
-- SMALLEST only when the set is not empty
function EMPTY return BOOLEAN;

1. Priority
   a. Criteria
   b. process with highest priority
   c. 1/o - PCPS
   d. SIF - special case p = 0
   e. Assumption: low number ★ high priority
   f. Priorities
      1. defined internally
         a. time limits
         b. memory requirements
         c. number of open files
         d. average I/O-burst/average CPU-burst
      2. defined externally
         a. importance of the process
         b. type and amount of funds being paid for computer use
         c. political and other factors
   g. Problems
      Indefinite blocking (starvation) - steady-stream of high-priority processes
      Solution: aging - gradually increasing the priority of processes
   h. Type
      1. preemptive: priority next process > priority running process
      2. nonpreemptive
   i. Round-Robin (RR)
      1. Criteria
         a. time quantum (10-100 ms) (time set to interrupt after one time quantum)
      2. Ready queue - circular FIFO
      3. Average waiting time is long
      4. Performance depends on the size of the time quantum; very small quantum θ processor sharing
      5. Problems: Context switching - solution: time quantum θ context-switch time
      6. Type: preemptive
   j. Multilevel Queue
      1. Criteria
         a. different ready queues (foreground queue - interactive processes, background queue - batch processes, system processes, interactive editing processes,...)
      2. process permanently assigned to one queue
      3. each queue has its own scheduling algorithm
      4. scheduling between the queues: fixed-priority preemptive scheduling or time-slicing
      5. Problems: not flexible - process remains permanently into the assigned queue
   k. Multilevel Feedback Queue
      1. Criteria
         a. process may move between queues
      2. entering queue
      3. criteria for upgrade (ex. I/O-bound)
      4. criteria when to demote (ex. long waiting time)
   l. Queued-Based Scheduling
      Make realistic promises about performance and live up to them
      Ex. if there are 4 users logged in, each will receive 1/4 of the CPU power
      System must
      a. keep track of how much CPU time a user has had for all his processes since login and how long has been logged in
Lecture Five

1. Compute the amount of CPU each user is entitled to:
   \[ \frac{\text{time since login}}{n} \]  
   (dynamic)

2. Compute:
   \[ \frac{\text{actual CPU time used}}{\text{CPU time entitled}} \]

3. Run the process with the lowest ratio
4. Reschedule when the ratio has moved above its closest competitor

Ex. real-time system: process in greatest danger of missing its deadline

Multiple Processors

- Types of processors
- Heterogeneous systems
  - Own queue
  - Own scheduling
- Homogeneous systems
  - Load sharing
  - Queue

- Self-scheduling
- Synchronization and mutual exclusion
- Not to pick the same process (common data structure)

- Master-slave structure
  - One processor scheduler
  - Asymmetric multiprocessor
  - Heavy scheduling load
  - Master processor
  - Overloaded (bottleneck)

Conclusion

- Separate scheduling mechanisms and scheduling policies
- Scheduling algorithm is parametrized in some way, but the parameters can be filled in by the user processes (dynamically, rare?)

Deadlock Concept and Characterization

- System Modeling
  - Finite number of resources partitioned into several types consisting of some number of identical instances
  \[ R = \{ (R_1, n_1), (R_2, n_2), \ldots, (R_m, n_m) \} \]
  - Finite number of processes
  \[ P = \{ P_1, P_2, \ldots, P_k \} \]
  - Request resource (system calls or wait and signal operations)
  - Use resource
  - Release resource (system calls or wait and signal operations)
  - Resource-allocation graph

![Resource-allocation graph](image)

Figure 5.2. Example of the resource-allocation graph

4
Lecture Five

Deadlock Characterization
A set of processes is in a deadlock state when every process in the set is waiting for an event that can be caused only by another process in the set.

Figure 5.3. Illustration of deadlock

Necessary conditions for deadlock:
1. mutual exclusion (at least one resource must be un sharable)
2. hold and wait
3. no preemption
4. circular wait

Situations other than deadlock with no progress:
1. livelock (busy waiting on a condition that can never become true)
2. starvation (process is indefinitely postponed)
Lecture Six

Textbook
Abraham Silberschatz, James L. Peterson, Peter B. Galvin
"Operating System Concepts", Addison-Wesley, third edition, 1991, Part 2, Chapter 6 (6.3 - 6.7) and Part 3, Chapter 7

References
1 Andrew S. Tanenbaum
"Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 6 (6.3 - 6.6) and Chapter 3 (3.1 - 3.2)
2 Jean Bacon
"Concurrent Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapter 6 (6.2 - 6.6), Chapter 3 (3.1 - 3.2)

Goals
1 To introduce different techniques for deadlock handling
2 To present concepts of memory management
3 To discuss approaches to physical memory management

Content
1 Deadlocks (1 hour)
   2 Deadlock Handling
2 Physical and Virtual Memory Allocation (2 hours)
   3 Memory Management
Lecture Six

Deadlock Handling

- Osnik algorithm
- Ensure that the system will never enter a deadlock state
  - deadlock prevention
    - Ensures that at least one of the necessary conditions does not hold
  - deadlock avoidance
    - The maximum number of resources is defined by
      - the number of available resources
      - the number of allocated resources
      - maximum demand
    - A state is safe if the system can allocate resources to each process up to its maximum in some order and still avoid deadlock
  - Banker's algorithm
    - Allocate the system to enter a deadlock state and then recover
    - First, detection algorithm - when it should be invoked?
    - How often is deadlock likely to occur?
    - How many processes will be affected by deadlock when it happens

Recovery algorithm

- Process termination
  - Short all deadlocked processes
  - Short one process at a time until the deadlock cycle is eliminated
- Resource preemption
  - Selecting a victim
  - Rollback
  - Starvation

Memory Management

- Memory management without swapping or paging
  - Monoprocessor
  - Multiprocessor and memory usage
  - Multiprocessor with fixed partitions
- Swapping
  - Multiprocessor with variable partitions
  - Block Maps
  - Linked Lists
  - Buddy system
  - Allocation of Swap Space
Lecture Seven

Textbook

Abraham Silberschatz, James L. Peterson, Peter B. Galvin

References

○ Andrew S. Tanenbaum
  "Modern Operating Systems", Prentice-Hall, 1992, Part 1, Chapter 3 (3.3 - 3.8) and Chapter 5 (5.1 - 5.2)
○ Jean Bacon
  "Concurrency Systems - An Integrated Approach to Operating Systems, Database, and Distributed Systems", Addison-Wesley, 1993, Chapter 3 (3.1 - 3.3)

Goals

○ To introduce concepts of virtual memory
○ To discuss a device management through the introductory example of device driver

Content

○ Physical and Virtual Memory Allocation (2 hours)
  ○ Virtual Memory
○ Device Management (1 hour)
Virtual Memory

- Demand Paging
  - Page Tables and Inverted Page Tables
  - Paging Hardware
  - Associative Memory
  - Page Replacement

- Page- Replacement Algorithms
  - Optimal Algorithm
  - Least-Recently-Used Algorithm
  - FIFO Algorithm
  - Second Chance Algorithm
  - Clock Algorithm
  - Least Frequently Used Algorithm
  - Simulating LRU in software

- buddy's memory
- Stack Algorithms
- Predicting page fault rate
- Working Set Model
- Page size
- Allocation of Frames
- Trashing
- Demand Segmentation
- Segmentation with paging

Device Management

- Principles of I/O hardware
  - I/O devices
  - Device Controllers
  - Direct Memory Access (DMA)
- Principles of I/O software
  - goals
  - interrupt handlers
  - device drivers

```
task PRINTER_DRIVER is
  entry PRINT(LINE);
  entry READY; /* printer ready for next character */
  for READY use at 16#800;
  end PRINTER_DRIVER:

task body PRINTER_DRIVER is
  type STATUS_REGISTER is
    interrupt_enabled: BOOLEAN;
    chain_running: BOOLEAN;
    end record;
  for STATUS_REGISTER use
    interrupt_enabled at 0 RANGE 3.5;
    chain_running at 3 RANGE 0;
    end record;
  for STATUS_REGISTER_SIZE use 2;
  -- allocate one word (two bytes per word assumed)
  line_length: constant := 152;
  subtype LINE is STRING(1 .. line_length);
  PRINTER_REGISTER: STATUS_REGISTER;
  for PRINTER_REGISTER use at 16#3FF400;
  BUFFER: LINE;
  PRINTER_BUFFER: CHARACTER;
  for PRINTER_BUFFER use at 16#3FF420;

begin
  PRINTER_REGISTER.interrupt_enabled := TRUE;
  PRINTER_REGISTER.chain_running := FALSE;
```
Lecture Seven

loop
  select
    accept PRINT(L: LINE) do
      BUFFER := L;
      end PRINT;
    if not PRINTER_REGISTER.CHAIN_RUNNING then
      PRINTER_REGISTER.CHAIN_RUNNING := TRUE;
      delay 1.0;
      end if;
    for i in 1..LINE_LENGTH loop
      PRINTER BUFFER := BUFFER(I);
      accept READY;
      exit when BUFFER(I) = ASCII LF or BUFFER(I) = ASCII FF;
      end loop;
    or
      when PRINTER_REGISTER.CHAIN_RUNNING =>
      delay 10.0;
      PRINTER_REGISTER.CHAIN_RUNNING := FALSE;
    end select;
  end loop;
end PRINT DRIVER;

① device-independent I/O software
② user-space I/O software
APPENDIX B

CS495 SAFETY CRITICAL SOFTWARE ENGINEERING
WITH ADA

ADA CLASS REPORT
STATEMENT OF THE PROBLEM

Most Department of Defense (DoD) contractors currently use the Ada programming language, primarily because DoD mandates its use. As shown by a recent article in Ada Letters\(^1\) it is used extensively outside of the defense community:

Although Ada was originally designed to provide a single flexible yet portable language for real-time embedded systems to meet the needs of the US DoD, its domain of application has expanded to include many other areas, such as large-scale information systems, distributed systems, scientific computation, and systems programming. Furthermore, its user base has expanded to include all major defense agencies of the Western world, the whole of the aerospace community and increasingly many areas in civil and private sectors such as telecommunications, process control and monitoring systems. Indeed, the expansion in the civil sector is such that civil applications now generate the dominant revenues of many vendors.

But too few commercial developers use Ada to make it one of the most popular languages. Part of the reason for this is that new graduates do not come with a knowledge of Ada. Commercial employers who might be considered prime candidates to use Ada are thus faced with additional training time and costs. Worse yet, few in commercial organizations are familiar with the benefits of using Ada. Even safety-critical applications that need Ada the most are often developed by practitioners untrained in software engineering principles\(^3\):

The mistakes that were made are not unique to this manufacturer but are, unfortunately, fairly common in other safety-critical systems. As Frank Houston of the US Food and Drug Administration (FDA) said, "A significant amount of software for life-critical systems comes from small firms, especially in the medical device industry; firms that fit the profile of those resistant to or uninformed of the principles of either system safety or software engineering."

Furthermore, these problems are not limited to the medical industry. It is still a common belief that any good engineer can build software, regardless of whether he or she is trained in state-of-the-art software engineering procedures.

IIT teaches many foreign-born students in the Computer Science (CS) Department. Because it is more difficult for foreign-born students to obtain a security clearance, very few obtain jobs with firms doing primarily DoD software development. Therefore, the Ada mandate means little or nothing to these students.
APPROACH TO A SOLUTION

To attract foreign-born students to an Ada class, IIT emphasizes the benefits of using Ada for typical application areas. One such area is safety-critical software. IIT offered a CS 495 course in the summer 1993 term called, "Safety-Critical Software Engineering With Ada." The announcement in Attachment A described some of the benefits of using modern software engineering approaches—including the use of Ada—to this application area.

The course instructor, Fred Francl, surveyed the class at the start of the first class. Attachment B presents the results of this survey of what each student hoped to get out of this class. This survey shows that all but one of the students surveyed mentioned Ada as the major attraction of this course. This was somewhat surprising because the course announcement (Attachment A) listed Object-Oriented (OO) techniques as one of the course features. Despite the current popularity of OO techniques, only two students in the survey listed them as a course priority.

The two-credit course covered the first edition of Software Engineering With Ada by Grady Booch. Attachment C shows how each chapter was weighted. The course introduced the Ada features most widely used in DoD projects, offered industry experience with these features, starting in the early eighties and including current experiences. These examples showed how these Ada features helped to integrate modern software engineering principles into the product.

Attachment D presents some of the viewgraphs developed for this course. They were designed to emphasize the advantages of the Ada features being taught. Where appropriate, Ada features were directly compared to features of other popular languages.

The strategy in presenting virtually all Ada features was to give the students the sense that Ada is a general-purpose language. The instructor reinforced this by using Ada in class problems and homework problems to implement solutions to diverse applications. The course also highlighted the improvements offered by Ada 9X in writing asynchronous tasks and in supporting object-oriented design. The instructor included coding examples to help make Ada 9X features seem more real to the students.

The tests stressed the Ada language features that bore directly on the needs of safety-critical software engineering. The midterm and final exams, which expresses this emphasis, are included in Attachments E and F, respectively.

To obtain a larger enrollment, IIT offered this course over a closed-circuit TV network (IITV). This allowed IIT to tape the course in VHS format. IIT is delivering this tape as part of the Final Report material.
RESULTS AND CONCLUSIONS

At the end of the Final Exam, the instructor asked if anyone felt his or her goals in taking the course were NOT met. Nobody responded, suggesting that the goals had been met reasonably well. Several students volunteered after class that they had really enjoyed this course despite the work involved in covering so much material so quickly.

All indications are that the course did give the students a good sense of the benefits of using Ada in safety-critical applications. The payoff will come when they join industry software groups and spread the Ada message to their colleagues.

FOLLOW-UP PLANS

1. IIT has scheduled this course to be given again in the Spring semester. IIT will make another video tape, with the idea that the second offering of a new course usually goes more smoothly than the first.

2. IIT is offering other courses using Ada, such as an Operating Systems course. This is possible now that a course that actually teaches the language is available in the curriculum. Ada is the teaching language of choice for these courses because of its power and expressiveness.

3. IIT plans to disseminate the improved video tape of this course to instructors at other colleges and universities who are in the process of developing a similar course.

4. IIT plans to purchase several copies of Ada compilers and Ada tutorials that can be run by individual students on PCs. This will allow students in courses that use Ada to learn or relearn it at their own pace.

REFERENCES


ATTACHMENT A

ADA CLASS ANNOUNCEMENT
CS 495 SAFETY-CRITICAL SOFTWARE ENGINEERING WITH ADA

Who should enroll? Software students and practitioners with at least one year of programming experience.

In this course you will learn to:

* Use Ada, the language being adopted world-wide to implement the most difficult software systems.

* Use Ada programming features that help NASA, the FAA and the military develop software for systems that can’t afford surprise behavior.

* Use Ada programming features that help one of the world’s largest telephone companies to develop systems that work better and cost less.

* Avoid the three technical problems facing new Ada users.

* Use Ada 9X with Object Oriented Analysis and Design methods.

* Double your personal programming productivity and then double it again with more practice.

* Understand how to change your approach when you are a member of a very large software engineering team.

When: IIT Summer Session, Fridays, 3:10 to 6:50 PM.

Where: Rice Campus. Also on TV for other locations.

Credit: Two credit hours. (Discuss with contacts listed below.)

Text: Grady Booch, Software Engineering With Ada

Instr: Fred Francl managed real-time, mission-critical software engineering development for over fifteen years. He led several government studies on the effectiveness of Ada for this type of software development. He served for three years as a Distinguished Reviewer for an Ada Joint Program Office team. Mr. Francl led the Real-Time Session of a national Ada conference. He currently consults with the Federal Aviation Administration on Ada issues that arise in the modernization of the U.S. Enroute Navigation System. He chairs the Chicago Chapter of the ACM Special Interest Group on Ada (SIGAda).

ATTACHMENT A
Contacts:  
Dr. Tzila Elrad (312)567-5142  CSELRAD@minna.acc.iit.edu  
Mr. Fred Franci (708)627-8098  ffrancl@ajpo.sei.cmu.edu

ATTACHMENT A
ATTACHMENT B

ADA CLASS SURVEY RESULTS
<table>
<thead>
<tr>
<th>Student #</th>
<th>Class Learning Goals</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Ada</td>
</tr>
<tr>
<td>2</td>
<td>Ada</td>
</tr>
<tr>
<td>3</td>
<td>How Ada fits applications, how it supports OO</td>
</tr>
<tr>
<td>4</td>
<td>Real-time OO and Software Engineering principles</td>
</tr>
<tr>
<td>5</td>
<td>Ada</td>
</tr>
<tr>
<td>6</td>
<td>Ada and Software Engineering principles</td>
</tr>
<tr>
<td>7</td>
<td>Applying Ada to real-world problems</td>
</tr>
<tr>
<td>8</td>
<td>Ada knowledge</td>
</tr>
<tr>
<td>9</td>
<td>Ada knowledge</td>
</tr>
<tr>
<td>10</td>
<td>Relearn Ada (learned from manual 10 years ago)</td>
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<tr>
<td>11</td>
<td>Ada</td>
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ATTACHMENT B
ATTACHMENT C

TEXT CHAPTER WEIGHTING
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<tr>
<td>1</td>
<td>A</td>
<td>Includes lecture material not in book</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>Includes lecture material not in book</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
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</tr>
<tr>
<td>4</td>
<td>A</td>
<td>Especially 6-step Booch OO method</td>
</tr>
<tr>
<td>5</td>
<td>A</td>
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<tr>
<td>6</td>
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<tr>
<td>14</td>
<td>C</td>
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<tr>
<td>15</td>
<td>D</td>
<td></td>
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<td>16</td>
<td>B</td>
<td>Be able to write task specs, to read task bodies</td>
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<td>23</td>
<td>F</td>
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</tr>
<tr>
<td>24</td>
<td>F</td>
<td>To be covered after Final Exam</td>
</tr>
</tbody>
</table>

A = Almost sure to be important in the final exam

F = Definitely not exam material. For familiarization only.
ATTACHMENT D

SAMPLE VIEW GRAPHS
ATTACHMENT E

MID-TERM EXAM
ADMINISTRIVIA
Please take this exam with a closed textbook and with a one hour time limit. When complete, give to the proctor and leave the classroom. Please return one hour after the test start time.

Record your answers on a sheet of your own paper with your name, "CS495 Mid-Term Exam" and today's date at the top of the page. If multiple pages are used, put your name and the page number at the top of each sheet.

PROBLEM TO SOLVE
Use the Booch Object-Oriented (OO) Development Method to specify an Ada software simulation of an automobile cruise control system. Assume it is to be run by a user called the driver who accesses each of the driver controls through the terminal and keyboard.

PROBLEM APPROACH TO USE
The first step in the Booch OO Development Method, Define the Problem, is provided on the following page. The final step, Implement Each Object, is not required. Doing the final step or some parts of it earns extra credit, but only if done well.

For each step in the Booch OO Development Method, enter and explain the results of your analysis on your test paper. For example, if a Booch OO Development Method step requires you to identify certain kinds of items, list the items on your test paper and explain your reason for choosing them.

Any code or pseudo-code produced should follow the Ada syntax rules as much as possible, but no points will be deducted for syntax errors. Please use comments to assure that your Ada code will be understandable even if the syntax is wrong.

Your solution will be graded on:
METHOD (How well the Booch OO Development Method is followed)
COMPLETENESS (Including any exceptions needed for safety)
CORRECTNESS (With respect to the statement of the problem)
SIMPLICITY (No complexity not required by the problem)
READABILITY (Of Ada code or Ada pseudo-code produced)
STEP 1: DEFINE THE PROBLEM
A real automobile cruise control system maintains the speed set by the operator (driver) by pressing the accelerator when going up hills and releasing it when going down hills. This cruise control system shall be an abstraction or simulation of a real one.

The compiler shall supply the package Clock, which may be imported:

```pascal
package Clock is
    type Time_Type is private;
    function Current_Time
        return Time_Type; -- current clock time to the nearest msec
    function Add_1_Second
        (Current_Time: in Time_Type)
        return Time_Type; -- adds one second to Current_Time
    function Timer_Expired
        (Current_Time: in Time_Type
         Timer_Set_Time: in Time_Type)
        return Boolean; -- True if Current_Time > Timer_Set_Time
private
    type Time_Type is range 0..Long_Integer_Last;
end Clock;
```

The driver shall control the simulation with the following inputs:

1. **ON** shall display the current speed, randomly change speed each second by a small amount, and respond to all keys described below if the current state is **OFF**. Otherwise it shall do nothing.

2. **OFF** shall stop displaying the current speed, ignore all keys except the **ON** key, and erase any set speeds from memory if the current state is **ON**. Otherwise it shall do nothing.

3. **ACCELERATE** shall increase speed at a constant rate each second while its key is depressed. When its key is released the current speed shall be stored in memory as the set speed. This speed shall then remain constant.

4. **COAST** shall decrease speed at a constant rate each second while its key is depressed. When its key is released the current speed shall be stored in memory as the set speed. This speed shall then remain constant.

5. **BRAKE** shall decrease speed at a constant rate ten times that of the **COAST** key each second while its key is depressed. When its key is released the current speed shall be randomly changed by a small amount each second. The set speed (if **ACCELERATE** or **COAST** had previously stored it) shall remain in memory.

6. **RESUME** shall accelerate at the same rate as the **ACCELERATE** key or decelerate at the same rate as the **COAST** key until the set speed is reached. This speed shall then remain constant.
1. Assume each member of our class is to write a 100 page paper. If there are no misspellings, grammatical mistakes, or factual errors in any of the papers, then assume each member of the class gets $100,000. But if there is even one error in any of the papers, assume each member of the class will be killed.

   a. What things would you suggest doing or what things would you suggest obtaining to improve the chances for success?

   b. What things would you suggest doing or obtaining if each person had to write an error-free 10,000 lines of code portion of a software program instead of a 100 page paper?

   c. Assume there is a time limit of two years to finish the class software project. Further assume that the class has the usual distribution of software engineering productivity, and that the best in the class is ten times as productive as the worst in the class. What would you suggest doing to speed up the project to minimize the chances of being late without introducing fatal errors literally into the code?
2. Ada has been called a "large" language. Compared to Pascal it has many more built-in features, supporting such things as data abstraction, concurrent processing and machine-level operations (such as being able to load a register at a specific address with a specific hexadecimal value.)

a. When would it be an advantage to use a large language like Ada with these capabilities?

b. When would you be better off with a smaller language like Pascal?

3. Assume you work for a company that has standardized on the use of a single language for all its projects. This happens because companies often expect this standardization will make it easier to transfer engineers among projects and to reuse code.

a. What are the added advantages if that single language is Ada?

b. It is possible to write Ada-like code in another language, but the compiler will not enforce things like visibility rules. What are the advantages of designing as if you could use Ada and then enforcing needed rules such as object scope and visibility yourself?
4. Assume you work for a company that has standardized on a single design method. This happens because companies often expect this standardization will reduce expenditures for method support tools and/or method training courses.

   a. What are the added advantages if that single design method is Object-Oriented Development?

   b. What is the fastest-growing development method today?

5. A "hacker" can be defined as someone who designs software as quickly as possible, who loves to include optimizations, and who thinks a program is good enough if it "works" for his tests.

   a. What is your definition of a software engineer?

   b. When does a good software engineer add optimizations to the code?

   c. In a large, complex software project, we have learned in this course that *Quality if free*. *It is lack of quality that costs money.* Explain why this is true.
6. The first step in the Booch Object-Oriented (OO) Development method is to define the problem.

a. How do you use the problem definition to identify the objects?

b. How do you use the problem definition to identify the operations on each object?

c. How do you represent operations using Ada?

d. What kind of a diagram is suitable to establish the visibility of each object?

e. Which Ada language construct is especially suited to establishing the interface for each object?

f. Which Ada language construct is especially suited to implementing each object?
7. Ada is better than many traditional languages that were designed to support only procedural abstractions (such as could be gotten from a traditional flow chart.) Ada is designed to support data abstractions as well as procedural abstractions.

a. What Ada language construct do you use to express a data abstraction?

b. If only certain operations make sense to be used with this abstraction, how do you show this in Ada?

c. If the data abstraction has internal states (for example, is the German Shepherd object asleep or awake?) that must be considered to solve the problem, how do you show this in Ada?

d. What is an encapsulated type?

e. How is an encapsulated type shown in Ada?

f. What is a type attribute?

g. If a data abstraction occurs for a number of different types of object (such as a queue that can accept integers, real numbers, character strings, etc.), what Ada language construct do you use to avoid rewriting the abstraction for each type of object?
8. Older, traditional languages need to use data dictionaries and set/use tables (which show everywhere a variable value is set or used) to keep track of variables.

a. What features in Ada—if used properly—make data dictionaries unnecessary?

b. Certain variables are only used to indicate that abnormal processing must be done, or that an error condition has arisen. What special type does Ada assign to these variables?

9. Tasks are used to express concurrent action in Ada. They operate synchronously using a mechanism called the rendezvous.

a. What information about a task can you find in the task specification?

b. How does an operating system decide which task should run?

c. How do you show asynchronous concurrent action (for example, a mailbox) using Ada tasks?