Chapter 7

Slides from Stephen Schach and McGraw Hill

7.1 What Is a Module?

- A lexically contiguous sequence of program statements, bounded by boundary elements, with an aggregate identifier
  - "Lexically contiguous"
    - Adjoining in the code
  - "Boundary elements"
    - `{ ... }`
    - **`begin ... end`**
  - "Aggregate identifier"
    - A name for the entire module

Design of Computer

- A highly incompetent computer architect decides to build an ALU, shifter, and 16 registers with AND, OR, and NOT gates, rather than NAND or NOR gates

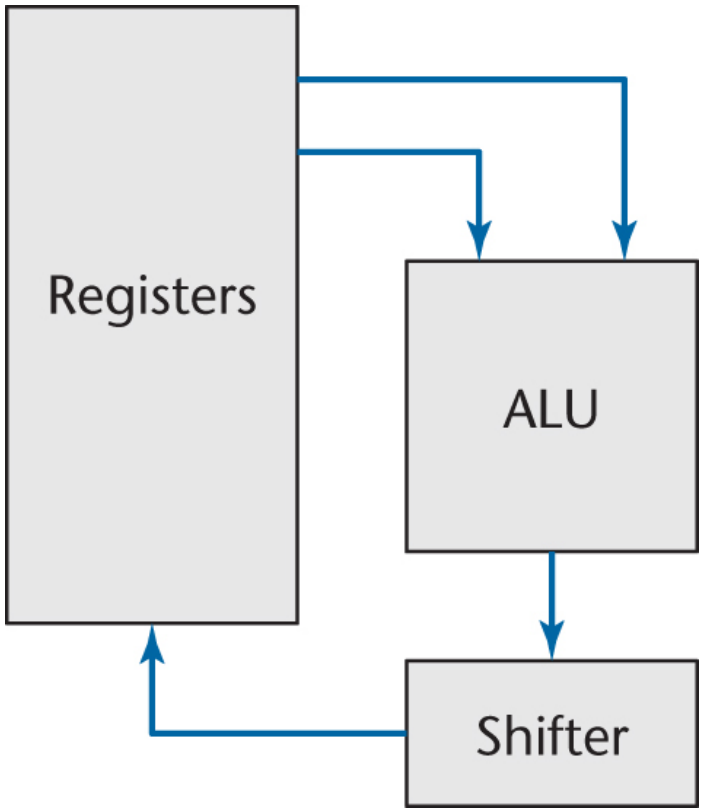


Figure 7.1

Design of Computer (contd)

- The architect designs three silicon chips

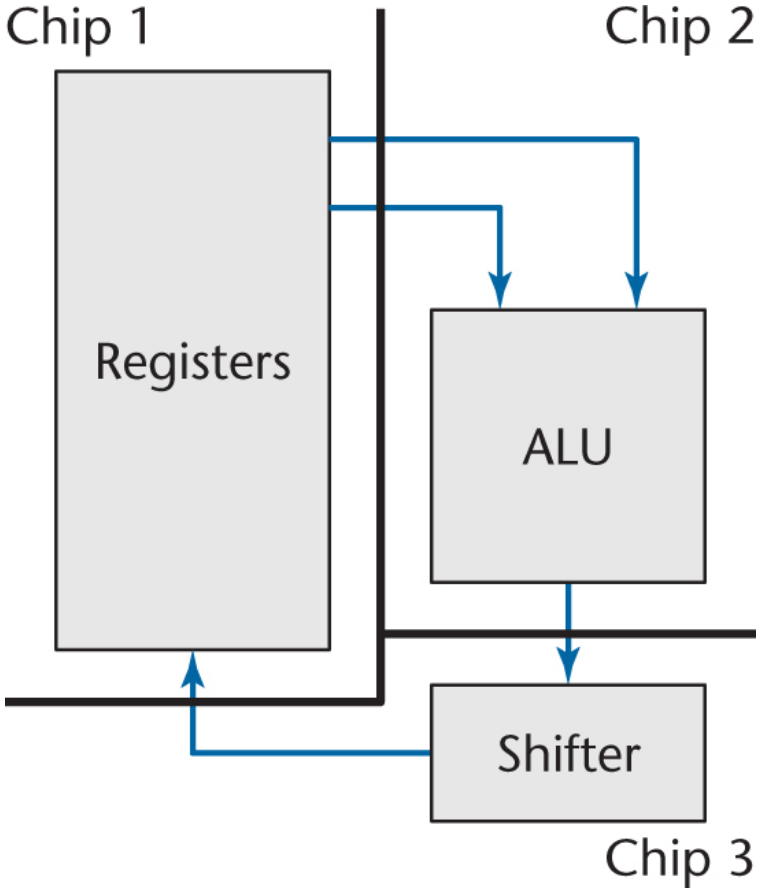


Figure 7.2

Design of Computer

- Redesign with one gate type per chip
- Resulting "masterpiece"

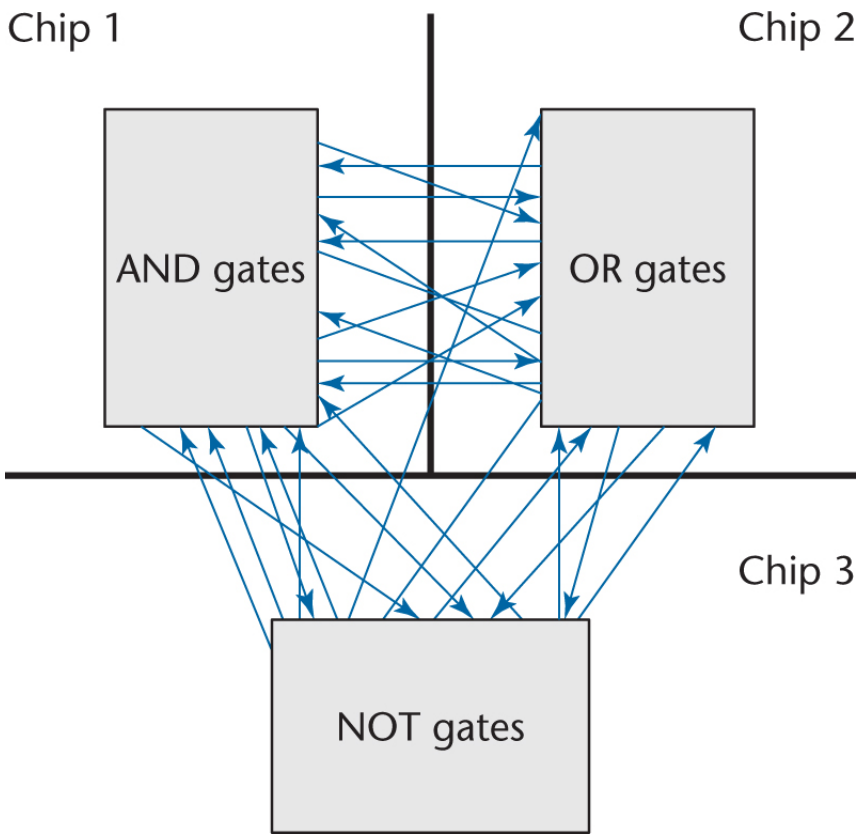


Figure 7.3

Computer Design

- The two designs are functionally equivalent
  - The second design is
    - Hard to understand
    - Hard to locate faults
    - Difficult to extend or enhance
    - Cannot be reused in another product

- Modules must be like the first design
  - Maximal relationships within modules, and
  - Minimal relationships between modules

Composite/Structured Design (C/SD p186)

- A method for breaking up a product into modules to achieve
  - Maximal interaction within a module, and
  - Minimal interaction between modules

- Module cohesion
  - Degree of interaction within a module

- Module coupling
  - Degree of interaction between modules

Function, Logic, and Context of a Module

- In C/SD, the name of a module is its function

- Example:
  - A module computes the square root of double precision integers using Newton's algorithm. The module is named `compute_square_root`

- The underscores denote that the classical paradigm is used here

7.2 Cohesion

- The degree of interaction within a module
- Seven categories or levels of cohesion (non-linear scale)

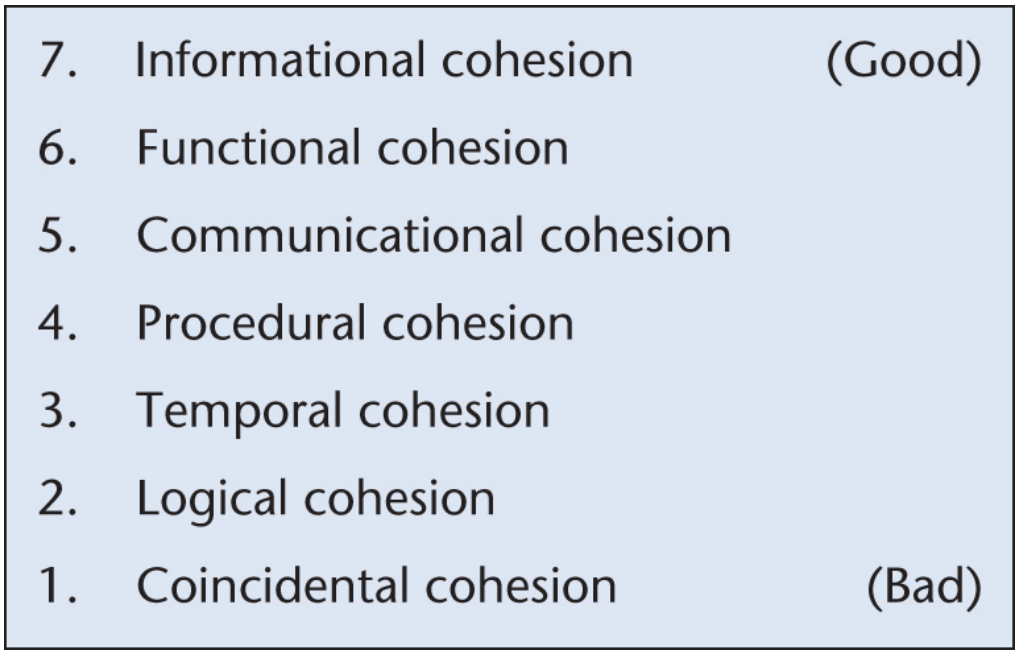


Figure 7.4

7.2.1 Coincidental Cohesion

- A module has coincidental cohesion if it performs multiple, completely unrelated actions

- Example:
  - `print_next_line, reverse_string_of_characters_comprising_second_parameter, add_7_to_fifth_parameter, convert_fourth_parameter_to_floating_point`

- Such modules arise from rules like
  - “Every module will consist of between 35 and 50 statements”

Why Is Coincidental Cohesion So Bad?

- It degrades maintainability
- A module with coincidental cohesion is not reusable
- The problem is easy to fix
  - Break the module into separate modules, each performing one task

7.2.2 Logical Cohesion

- A module has logical cohesion when it performs a series of related actions, one of which is selected by the calling module

Logical Cohesion (contd)

- Example 1:

```
function_code = 7;
new_operation (op code, dummy_1, dummy_2, dummy_3);
// dummy_1, dummy_2, and dummy_3 are dummy variables,
// not used if function code is equal to 7
```

- Example 2:
  - An object performing all input and output

- Example 3:
  - One version of OS/VS2 contained a module with logical cohesion performing 13 different actions. The interface contains 21 pieces of data

Why Is Logical Cohesion So Bad?

- The interface is difficult to understand
- Code for more than one action may be intertwined
- Difficult to reuse

Why Is Logical Cohesion So Bad?

- A new tape unit is installed
  - What is the effect on the laser printer?

1. Code for all input and output
2. Code for input only
3. Code for output only
4. Code for disk and tape I/O
5. Code for disk I/O
6. Code for tape I/O
7. Code for disk input
8. Code for disk output
9. Code for tape input
10. Code for tape output
⋮ ⋮ ⋮
37. Code for keyboard input

Figure 7.5

7.2.3 Temporal Cohesion

- A module has temporal cohesion when it performs a series of actions related in time

- Example:
  - `open_old_master_file, new_master_file, transaction_file, and print_file; initialize_sales_district_table, read_first_transaction_record, read_first_old_master_record (a.k.a. perform_initialization)`

Why Is Temporal Cohesion So Bad?

- The actions of this module are weakly related to one another, but strongly related to actions in other modules
  - Consider `sales_district_table`
- Not reusable
- Page 189

7.2.4 Procedural Cohesion

- A module has procedural cohesion if it performs a series of actions related by the procedure to be followed by the product

- Example:
  - `read_part_number_and_update_repair_record_on_master_file`

Why Is Procedural Cohesion So Bad?

- The actions are still weakly connected, so the module is not reusable

7.2.5 Communicational Cohesion

- A module has communicational cohesion if it performs a series of actions related by the procedure to be followed by the product, but in addition all the actions operate on the same data

- Example 1:

```
update_record_in_database_and_write_it_to_audit_trail
```

- Example 2:

```
calculate_new_coordinates_and_send_them_to_terminal
```

Why Is Communicational Cohesion So Bad?

- Still lack of reusability

7.2.6 Functional Cohesion

- A module with functional cohesion performs exactly one action

7.2.6 Functional Cohesion

- Example 1:
  - `get_temperature_of_furnace`
- Example 2:
  - `compute_orbital_of_electron`
- Example 3:
  - `write_to_diskette`
- Example 4:
  - `calculate_sales_commission`

Why Is Functional Cohesion So Good?

- More reusable
- Corrective maintenance is easier
  - Fault isolation
  - Fewer regression faults
- Easier to extend a product

7.2.7 Informational Cohesion

- A module has informational cohesion if it performs a number of actions, each with its own entry point, with independent code for each action, all performed on the same data structure

Why Is Informational Cohesion So Good?

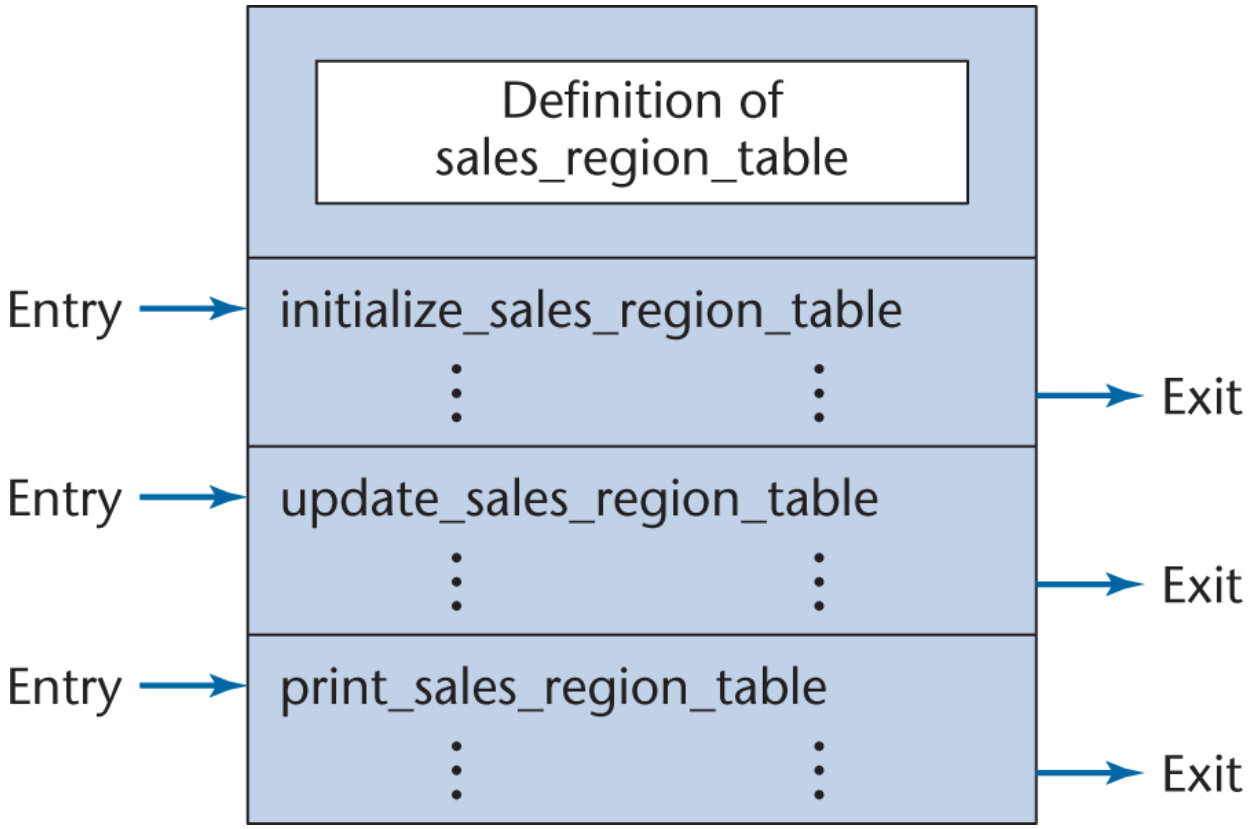


Figure 7.6

- Essentially, this is an abstract data type (see later)

7.3 Coupling

- The degree of interaction between two modules
  - Five categories or levels of coupling (non-linear scale)

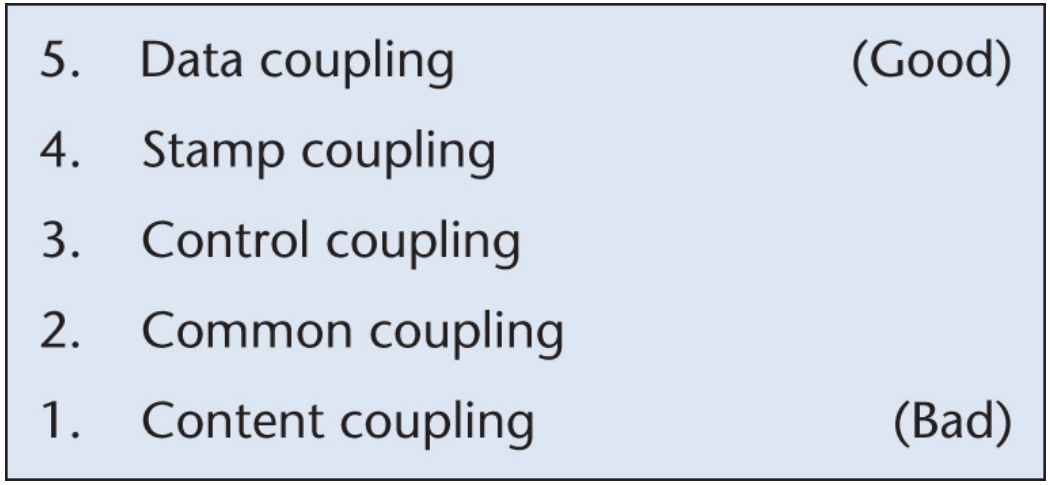


Figure 7.8

7.3.1 Content Coupling

- Two modules are content coupled if one directly **references contents of the other**

- Example 1:
  - Module `p` modifies a statement of module `q`

- Example 2:
  - Module `p` refers to local data of module `q` in terms of some numerical displacement within `q`

- Example 3:
  - Module `p` branches into a local label of module `q`

Why Is Content Coupling So Bad?

- Almost any change to module `q`, even recompiling `q` with a new compiler or assembler, requires a change to module `p`

7.3.2 Common Coupling

- Two modules are common coupled if they have write access to global data

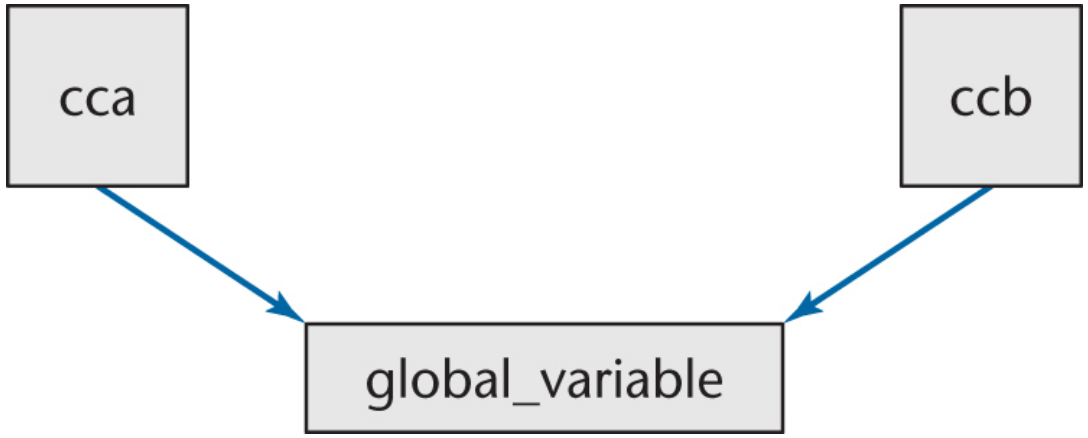


Figure 7.9

- Example 1
  - Modules `cca` and `ccb` can access *and change* the value of `global_variable`

7.3.2 Common Coupling

- Example 2:
  - Modules `cca` and `ccb` both have access to the same database, and can both read *and write* the same record

- Example 3:
  - FORTRAN **`common`**
  - COBOL **`common`** (nonstandard)
  - COBOL-80 **`global`**

Why Is Common Coupling So Bad?

- It contradicts the spirit of structured programming
  - The resulting code is virtually unreadable
  - **What causes this loop to terminate?**

```
whlle (global_variable == 0)
{
   if (argument_xyz > 25)
       module_3 ( );
   else
       module_4 ( );
}
```

Figure 7.10

Why Is Common Coupling So Bad?

- Modules can have side-effects
  - This affects their readability
  - Example: `edit_this_transaction (record_7)`
  - The entire module must be read to find out what it does
- A change during maintenance to the declaration of a global variable in one module necessitates corresponding changes in other modules
- Common-coupled modules are difficult to reuse

Why Is Common Coupling So Bad?

- Common coupling between a module `p` and the rest of the product can change without changing `p` in any way
  - *Clandestine common coupling*
  - Example: The Linux kernel (p194)

- A module is exposed to more data than necessary
  - This can lead to computer crime

7.3.3 Control Coupling

- Two modules are control coupled if one passes an element of control to the other

- Example 1:
  - An operation code is passed to a module with logical cohesion

- Example 2:
  - A control switch passed as an argument

Control Coupling (contd)

- Module `p` calls module `q`
- Message:
  - `I have failed` — data
- Message:
  - `I have failed, so write error message ABC123` — control

Why Is Control Coupling So Bad?

- The modules are not independent
  - Module `q` (the called module) must know the internal structure and logic of module `p`
  - This affects reusability

- Associated with modules of logical cohesion

7.3.4 Stamp Coupling

- Some languages allow only simple variables as parameters
  - `part_number`
  - `satellite_altitude`
  - `degree_of_multiprogramming`
- Many languages also support the passing of data structures
  - `part_record`
  - `satellite_coordinates`
  - `segment_table`

Stamp Coupling

- Two modules are stamp coupled if a data structure is passed as a parameter, but the called module operates on some but not all of the individual components of the data structure

Why Is Stamp Coupling So Bad?

- It is not clear, without reading the entire module, which fields of a record are accessed or changed
  - Example

    ```
    calculate_withholding (employee_record)
    ```

- Difficult to understand
- Unlikely to be reusable
- More data than necessary is passed
  - Uncontrolled data access can lead to computer crime

Why Is Stamp Coupling So Bad? (contd)

- However, there is nothing wrong with passing a data structure as a parameter, provided that *all* the components of the data structure are (required) accessed and/or changed

- Examples:

```
invert_matrix (original_matrix, inverted_matrix);
print_inventory_record (warehouse_record);
```

7.3.5 Data Coupling

- Two modules are data coupled if all parameters are homogeneous data items (simple parameters, or data structures all of whose elements are used by called module)

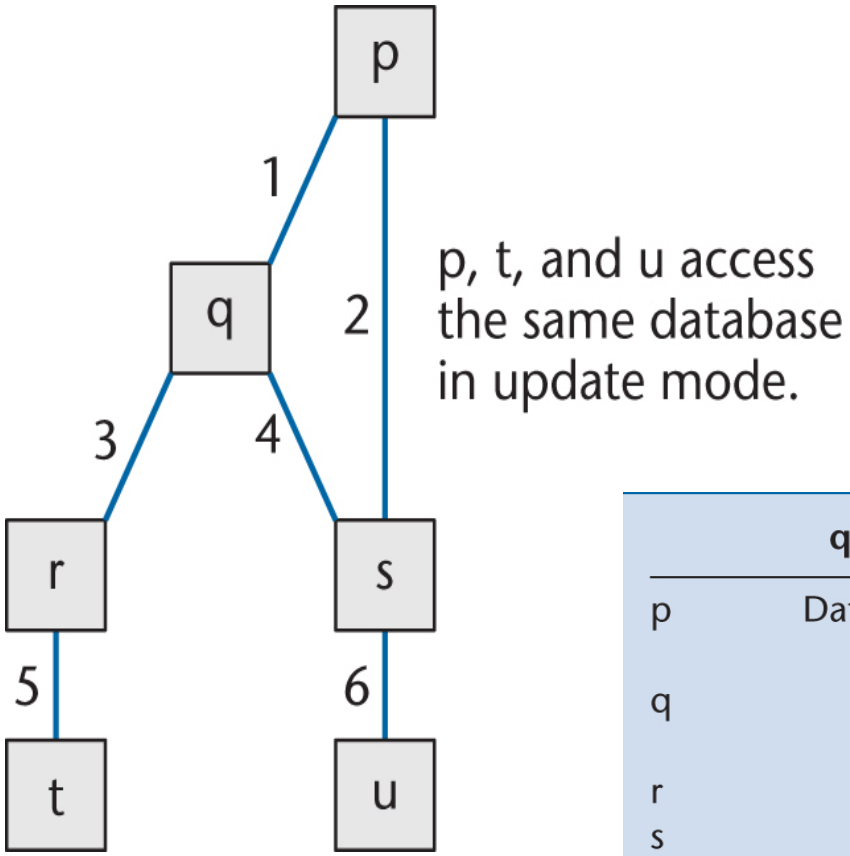
- Examples:
  - `display_time_of_arrival (flight_number);`
  - `compute_product (first_number, second_number);`
  - `get_job_with_highest_priority (job_queue);`

Why Is Data Coupling So Good?

- The difficulties of content, common, control, and stamp coupling are not present

- **Maintenance is much much easier**

7.3.6. Coupling Example

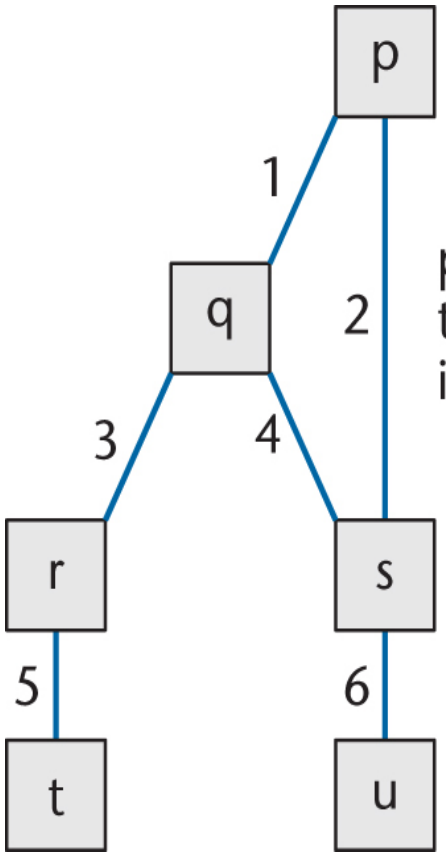


p, t, and u access the same database in update mode.

Figure 7.11

	q	r	s	t	u
p	Data	—	Data or stamp	Common	Common
q		Control	Data or stamp	—	—
r			—	Data	—
s				—	Data
t					Common

7.3.6. Coupling Example



p, t, and u access the same database in update mode.

Figure 7.11

Number	In	Out
1	aircraft_type	status_flag
2	list_of_aircraft_parts	—
3	function_code	—
4	list_of_aircraft_parts	—
5	part_number	part_manufacturer
6	part_number	part_name

Coupling Example (contd)

Number	In	Out
1	aircraft_type	status_flag
2	list_of_aircraft_parts	—
3	function_code	—
4	list_of_aircraft_parts	—
5	part_number	part_manufacturer
6	part_number	part_name

Figure 7.12

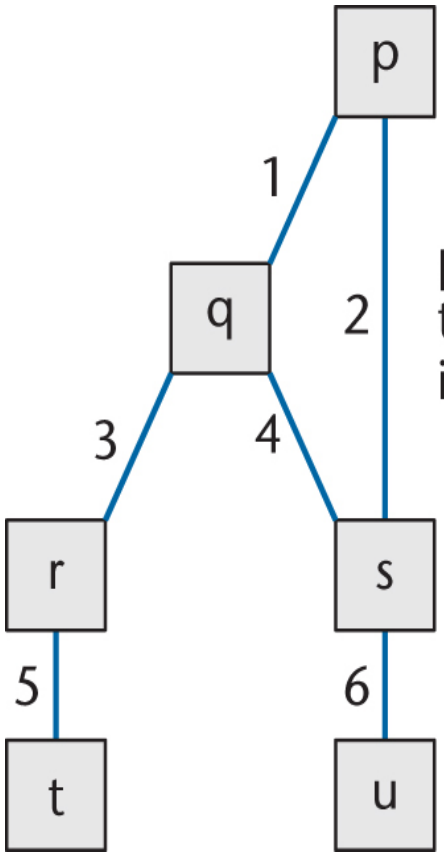
- Interface description

Coupling Example (contd)

	q	r	s	t	u
p	Data	—	Data or stamp	Common	Common
q		Control	Data or stamp	—	—
r			—	Data	—
s				—	Data
t					Common

Figure 7.13

- Coupling between all pairs of modules



p, t, and u access the same database in update mode.

Number	In	Out
1	aircraft_type	status_flag
2	list_of_aircraft_parts	—
3	function_code	—
4	list_of_aircraft_parts	—
5	part_number	part_manufacturer
6	part_number	part_name

	q	r	s	t	u
p	Data	—	Data or stamp	Common	Common
q		Control	Data or stamp	—	—
r			—	Data	—
s				—	Data
t					Common

Figure 7.11

7.3.7 The Importance of Coupling

- As a result of tight coupling
  - A change to module `p` can require a corresponding change to module `q`
  - If the corresponding change is not made, this leads to faults

- Good design has high cohesion and low coupling
  - What else characterizes good design? (see over)

Key Definitions

Abstract data type: a data type together with the operations performed on instantiations of that data type (Section 7.5)

Abstraction: a means of achieving stepwise refinement by suppressing unnecessary details and accentuating relevant details (Section 7.4.1)

Class: an abstract data type that supports inheritance (Section 7.7)

Cohesion: the degree of interaction within a module (Section 7.1)

Coupling: the degree of interaction between two modules (Section 7.1)

Data encapsulation: a data structure together with the operations performed on that data structure (Section 7.4)

Encapsulation: the gathering together into one unit of all aspects of the real-world entity modeled by that unit (Section 7.4.1)

Information hiding: structuring the design so that the resulting implementation details are hidden from other modules (Section 7.6)

Object: an instantiation of a class (Section 7.7)

re 7.14

7.4 Data Encapsulation

- Example
  - Design an operating system for a large mainframe computer. Batch jobs submitted to the computer will be classified as high priority, medium priority, or low priority. There must be three queues for incoming batch jobs, one for each job type. When a job is submitted by a user, the job is added to the appropriate queue, and when the operating system decides that a job is ready to be run, it is removed from its queue and memory is allocated to it

- Design 1 (Next slide)
  - Low cohesion — operations on job queues are spread all over the product

Data Encapsulation — Design 1

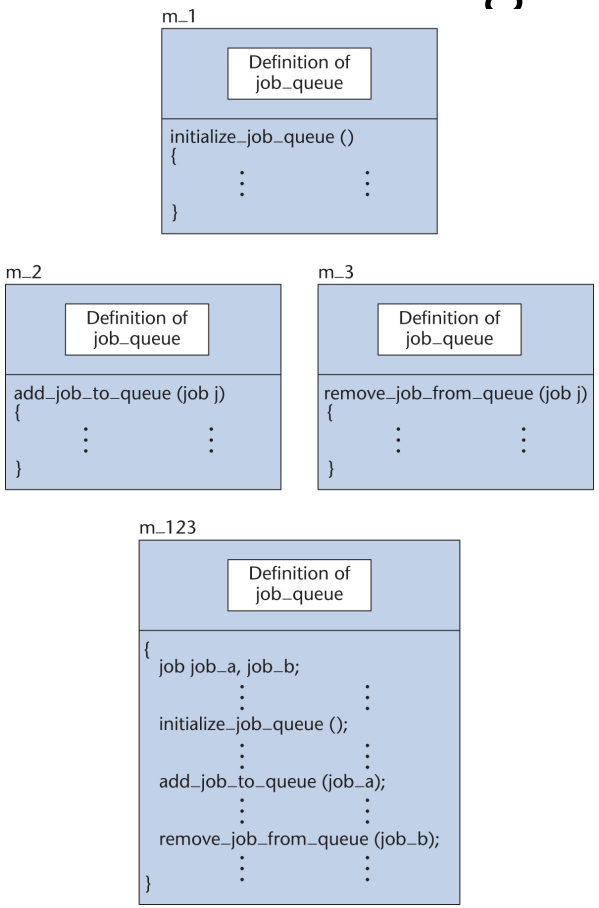
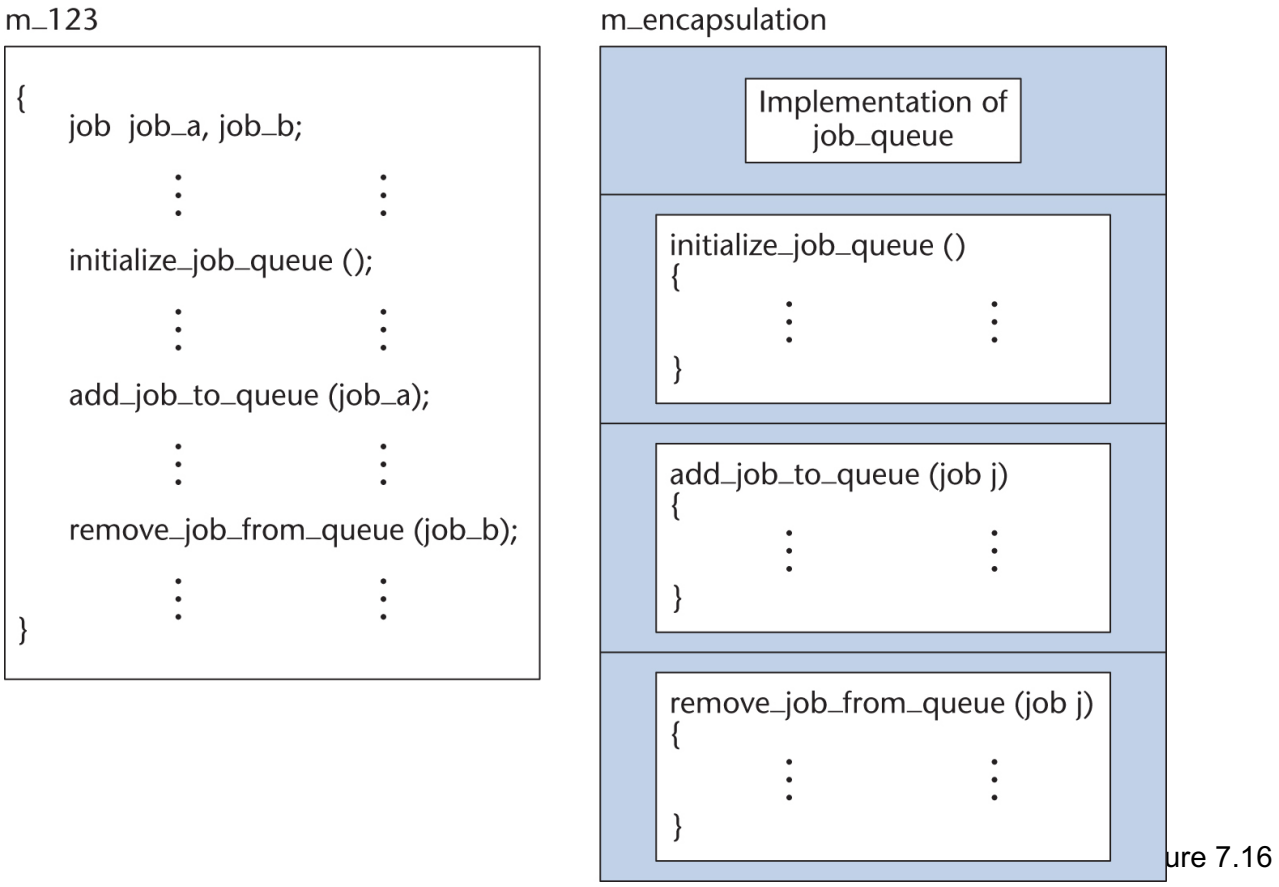


Figure 7.15

Data Encapsulation — Design 2



ure 7.16

Data Encapsulation (contd)

- `m_encapsulation` has informational cohesion
- `m_encapsulation` is an implementation of data encapsulation
  - A data structure (`job_queue`) together with operations performed on that data structure
- Advantages
  - Development
  - Maintenance

Data Encapsulation and Development

- Data encapsulation is an example of *abstraction*
- Job queue example:
  - Data structure
    - `job_queue`
  - Three new functions
    - `initialize_job_queue`
    - `add_job_to_queue`
    - `delete_job_from_queue`

7.4.1 Data Encapsulation and Development

- Abstraction
  - Conceptualize problem at a higher level
    - Job queues and operations on job queues
  - Not a lower level
    - Records or arrays

Stepwise Refinement

1. Design the product in terms of higher level concepts
   - It is irrelevant how job queues are implemented

2. Then design the lower level components
   - Totally ignore what use will be made of them

Stepwise Refinement

- In the 1st step, **assume the existence of the lower level**
  - Our concern is the behavior of the data structure
    - `job_queue`
- In the 2nd step, ignore the existence of the higher level
  - Our concern is the implementation of that behavior
- In a larger product, there will be many levels of abstraction

7.4.2 Data Encapsulation and Maintenance

- Identify the aspects of the product that are likely to change
- Design the product so as to minimize the effects of change
  - Data structures are unlikely to change
  - Implementation details may change
- Data encapsulation provides a way to cope with change

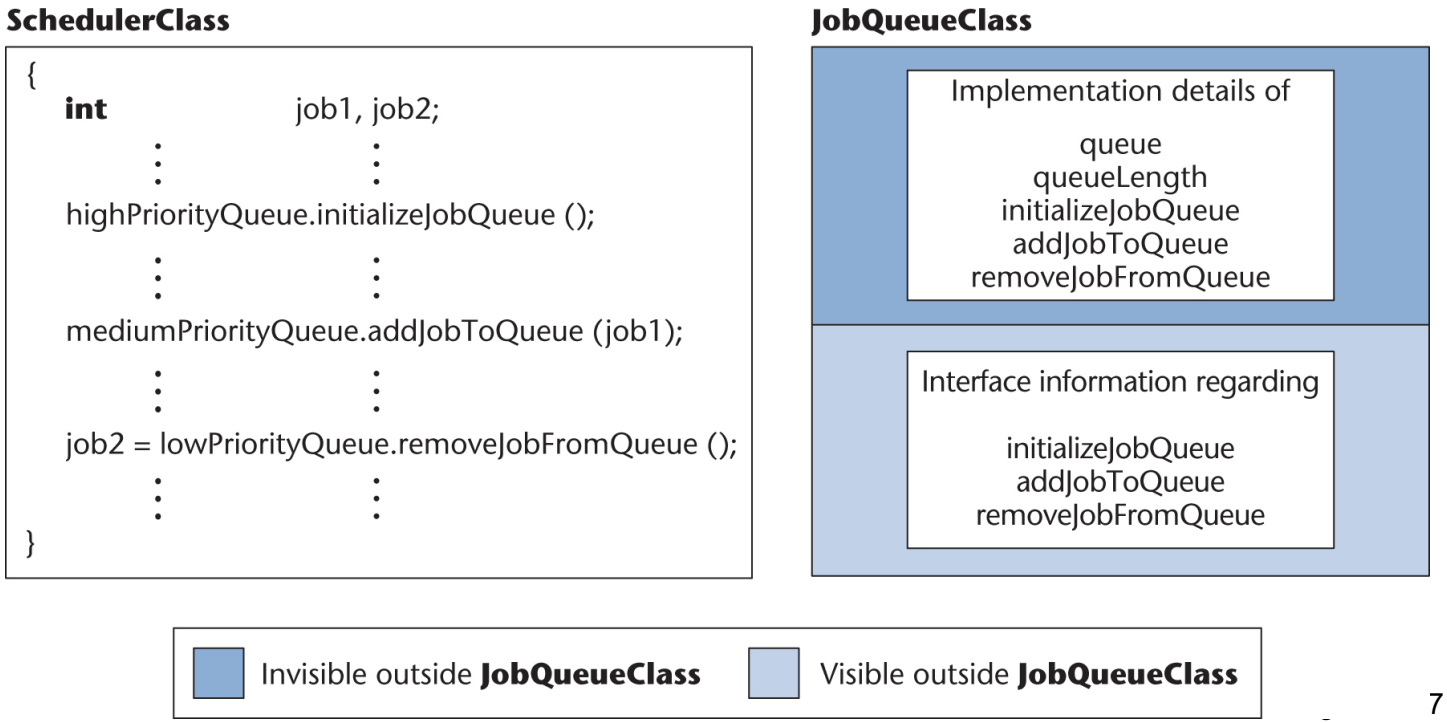
7.5 Abstract Data Types

- The problem with both implementations (shown in book page 204)
  - There is only one queue, not three
- We need:
  - Data type + operations performed on instantiations of that data type
- Abstract data type

7.6 Information Hiding

- Data abstraction
  - The designer thinks at the level of an ADT
- Procedural abstraction
  - Define a procedure — extend the language
- Both are instances of a more general design concept, *information hiding*
  - Design the modules in a way that items likely to change are hidden
  - Future change is localized
  - Changes cannot affect other modules

Information Hiding (contd)



- Effect of information hiding via `private` attributes

Major Concepts of Chapter 7

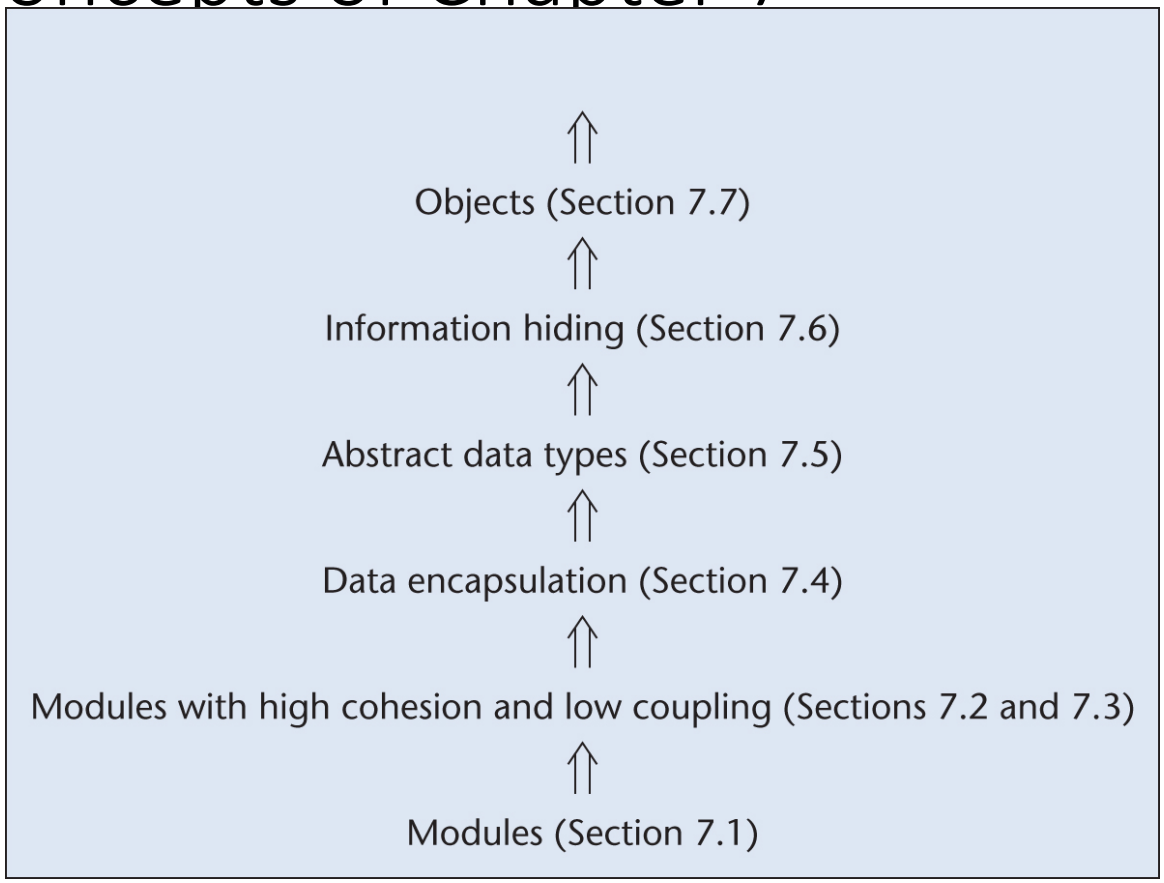


Figure 7.28