Planning a Software Project

UNIT-4

Agenda

- Background
- Effort estimation
- Schedule and resource estimation
- Quality Planning
- Risk management
- Project monitoring plans

Software Project

- Goal: Build a software system to meet commitments on cost, schedule, quality
- Worldwide - many projects fail
  - one-third are runaways with cost or schedule overrun of more than 125%

Project Failures

- Major reasons for project runaways
  - unclear objectives
  - bad planning
  - no project management methodology
  - new technology
  - insufficient staff
- All of these relate to project management
- Effective project management is key to successfully executing a project

Why improve PM?

- Better predictability leading to commitments that can be met
- Lower cost through reduced rework, better resource mgmt, better planning,..
- Improved quality through proper quality planning and control
- Better control through change control, CM, monitoring etc.

Why improve PM ....

- Better visibility into project health and state leading to timely intervention
- Better handling of risks reducing the chances of failure
- All this leads to higher customer satisfaction
- And organization improvement

The Project Mgmt Process

- Has three phases - planning, monitoring and control, and closure
- Planning is done before the much of the engineering process (life cycle, LC) and closure after the process
- Monitoring phase is in parallel with LC
- We focus on planning; monitoring covered through its planning

Project Planning

- Basic objective: To create a plan to meet the commitments of the project, I.e. create a path that, if followed, will lead to a successful project
- Planning involves defining the LC process to be followed, estimates, detailed schedule, plan for quality, etc.
- Main output - a project management plan and the project schedule

Key Planning Tasks

- Estimate effort
- Define project milestones and create a schedule
- Define quality objectives and a quality plan
- Identify risks and make plans to mitigate them
- Define measurement plan, project-tracking procedures, training plan, team organization, etc.

Effort Estimation

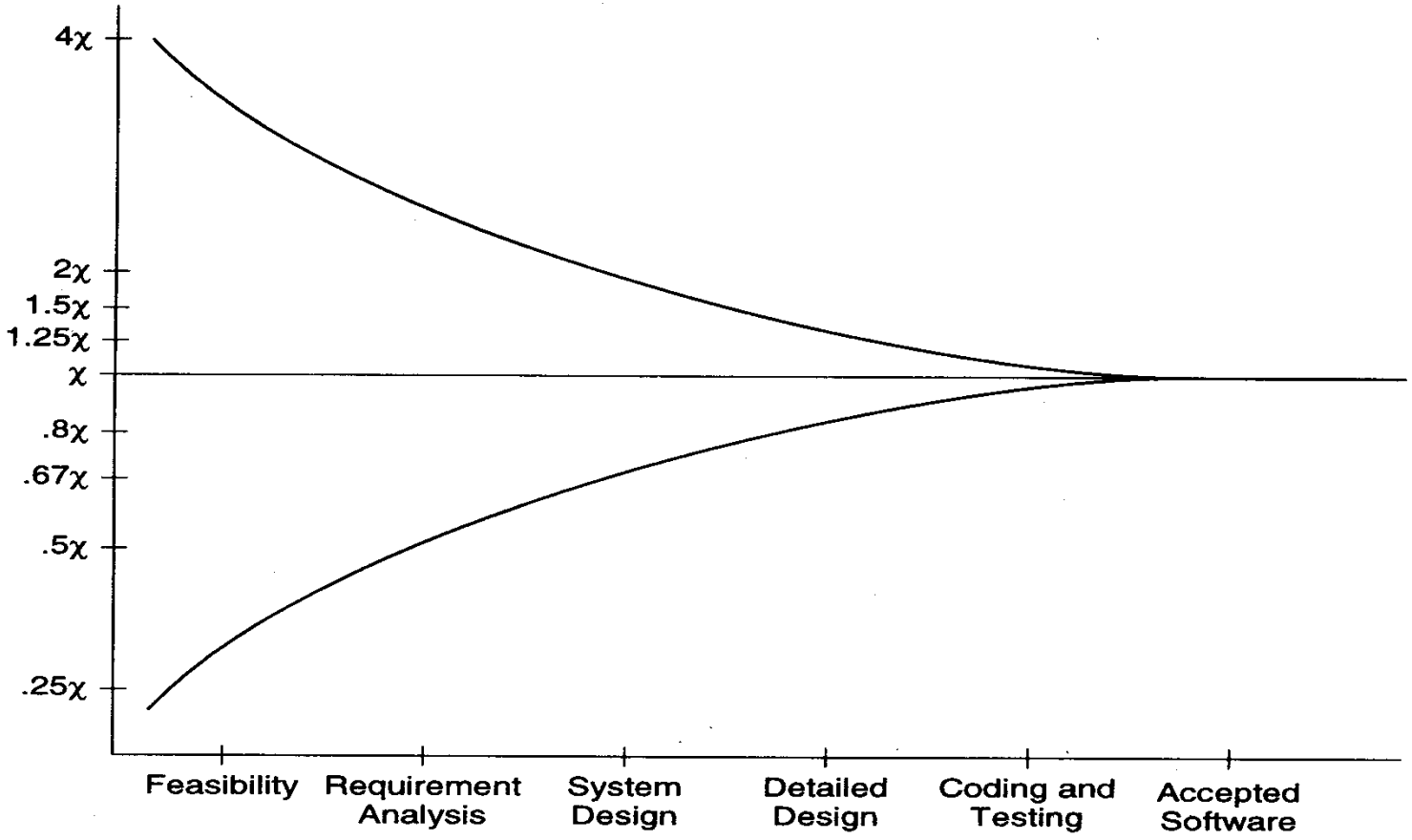
Effort Estimation

- For a project total cost and duration has to be committed in start
- Requires effort estimation, often in terms of person-months
- Effort estimate is key to planning - schedule, cost, resources depend on it
- Many problems in project execution stem from improper estimation

Estimation..

- No easy way, no silver bullet
- Estimation accuracy can improve with more information about the project
- Early estimates are more likely to be inaccurate than later
  - More uncertainties in the start
  - With more info, estimation becomes easier

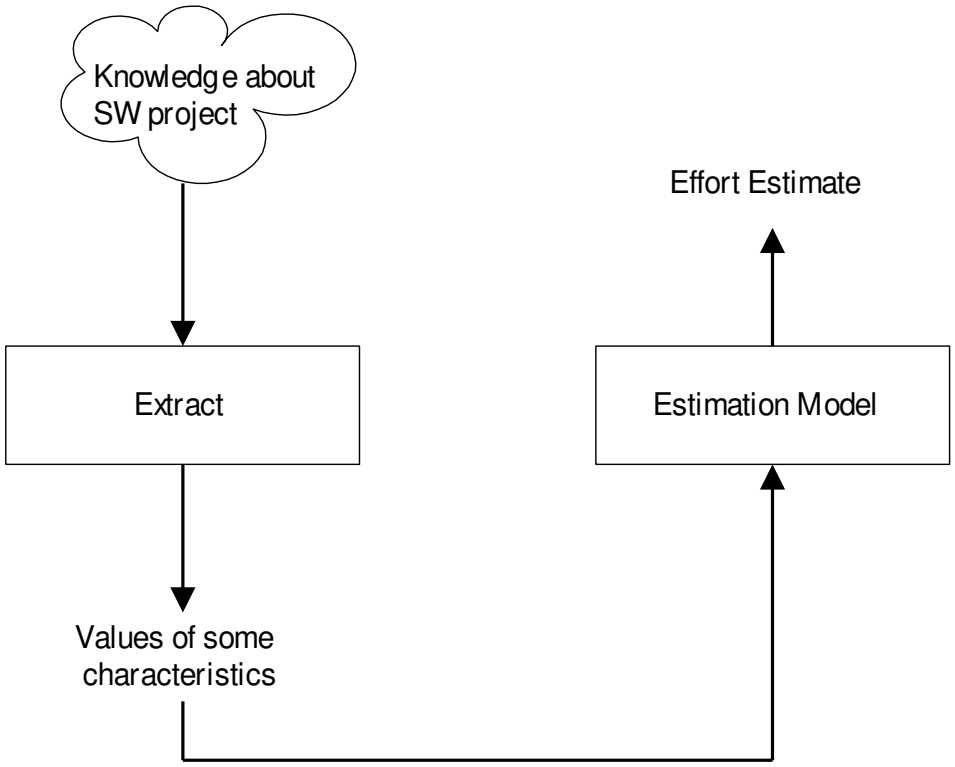
Estimation accuracy



Effort Estimation Models..

- A model tries to determine the effort estimate from some parameter values
- A model also requires input about the project, and cannot work in vacuum
- So to apply a model, we should be able to extract properties about the system
- Two types of models - top-down and bottom-up

Effort Estimation Models



Top down estimation

- First determines the total effort, then effort for components
- Simple approach – estimate effort from size and productivity
  - Get the estimate of the total size of the software
  - Estimate project productivity using past data and project characteristics
  - Obtain the overall effort estimate from productivity and size estimates
- Effort distribution data from similar project are used to estimate effort for different phases

Top-down Estimation

- A better method is to have effort estimate as a function of size using:

$$\text{Effort} = a * \text{size}^{b}$$

- E is in person-months, size in KLOC
- Incorporates the observation that productivity can dip with increased size
- Constants a and b determined through regression analysis of past project data

COCOMO Model

- Uses size, but adjusts using some factors
- Basic procedure
  - Obtain initial estimate using size
  - Determine a set of 15 multiplying factors from different project attributes
  - Adjust the effort estimate by scaling it with the final multiplying factor

COCOMO..

- Initial estimate: a * size ^{b} ; some standard values for a, b given for diff project types
- There are 15 cost driver attributes like reliability, complexity, application experience, capability, ...
- Each factor is rated, and for the rating a multiplication factor is given
- Final effort adjustment factor is the product of the factors for all 15 attributes

COCOMO – Some cost drivers

Cost Driver	Very low	Low	Nominal	High	Very High
Required reliability	.75	.88	1.0	1.15	1.4
Database size		.94	1.0	1.08	1.16
Product complexity	.7	.85	1.0	1.15	1.3
Execution time constraint			1.0	1.11	1.3
Memory constraint			1.0	1.06	1.21
Analyst capability	1.46	1.19	1.0	.86	.71
Application experience	1.29	1.13	1.0	.91	.82
Programmer capability	1.42	1.17	1.0	.86	.70
Use of software tools	1.24	1.10	1.0	.91	.83
Development schedule	1.23	1.08	1.0	1.04	1.1

COCOMO – effort distribution

- Effort distribution among different phases is given as a percent of effort
- Eg. For medium size product it is
  - Product design – 16%
  - Detailed design – 24%
  - Coding and UT – 38%
  - Integration and test – 22%

Bottom-up Estimation

- An alternate approach to top-down
- Effort for components and phases first estimated, then the total
- Can use activity based costing - all activities enumerated and then each activity estimated separately
- Can group activities into classes - their effort estimate from past data

An Estimation Procedure

- Identify programs in the system and classify them as simple, medium, or complex (S/M/C)
- Define the average coding effort for S/M/C
- Get the total coding effort.
- Use the effort distribution in similar projects to estimate effort for other tasks and total
- Refine the estimates based on project specific factors

Scheduling and Staffing

Project Schedule

- A project Schedule is at two levels - overall schedule and detailed schedule
- Overall schedule comprises of major milestones and final date
- Detailed schedule is the assignment of lowest level tasks to resources

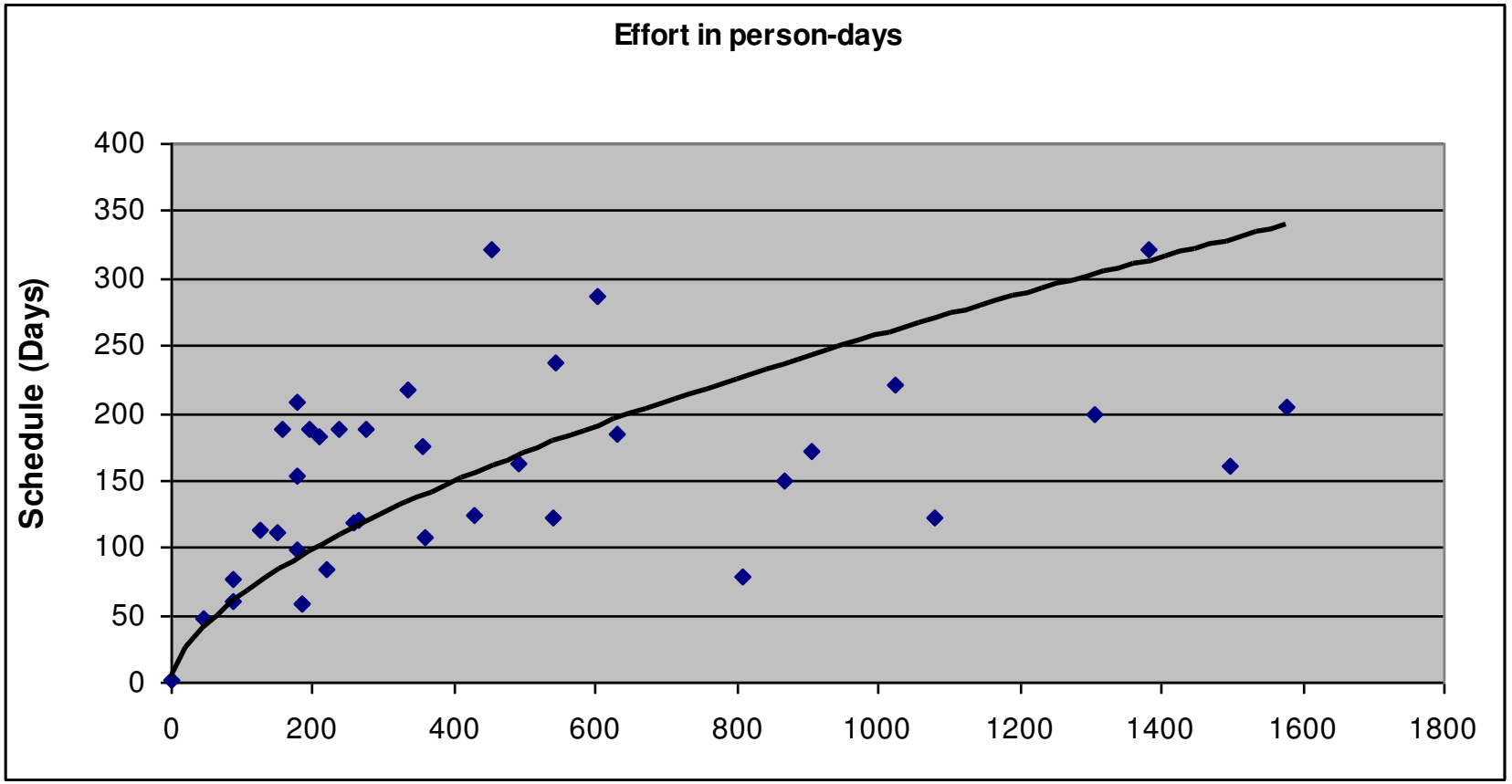
Overall Schedule

- Depends heavily on the effort estimate
- For an effort estimate, *some* flexibility exists depending on resources assigned
- Eg a 56 person-months project can be done in 8 months with 7 people, or 7 months with 8 people
- Stretching a schedule is easy; compressing is hard and expensive

Overall Scheduling…

- One method is to estimate schedule S (in months) as a function of effort in PMs
- Can determine the fn through analysis of past data; the function is non linear
- COCOMO: $S = 2.5\ E^{3.8}$
- Often this schedule is checked and corrected for the specific project
- One checking method – square root check

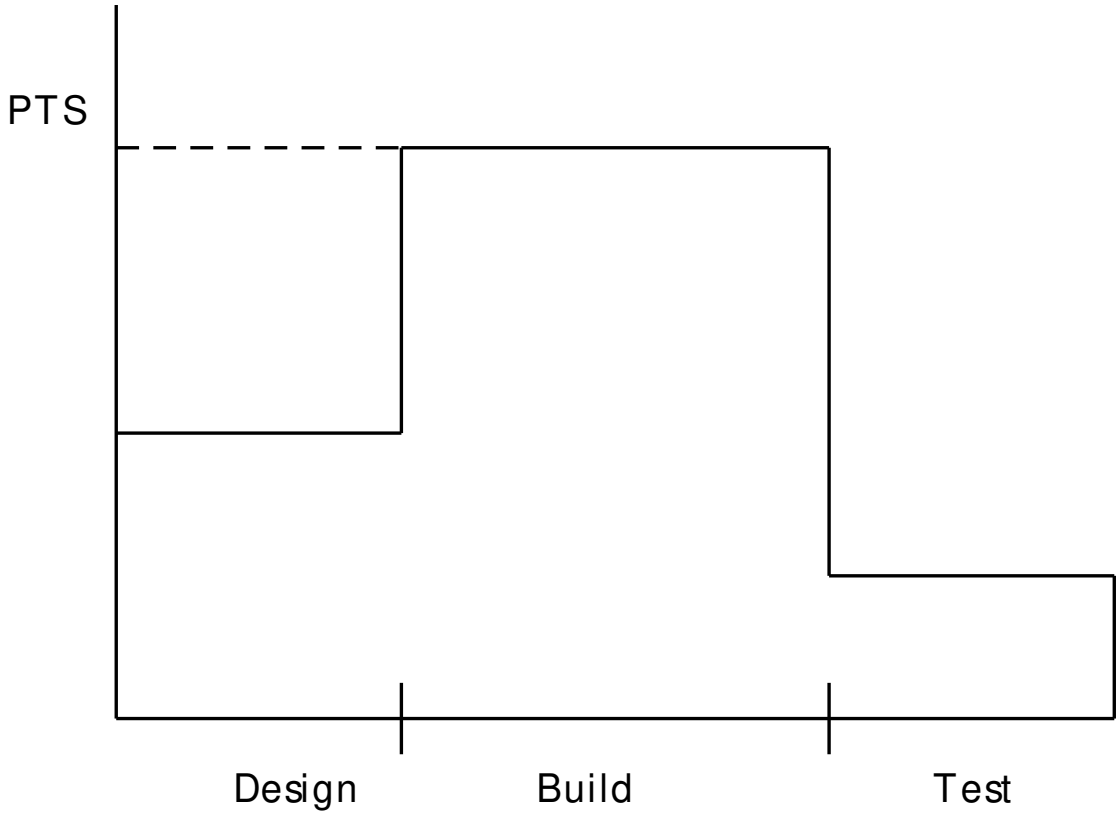
Determining Overall Schedule from past data



Determining Milestones

- With effort and overall schedule decided, avg project resources are fixed
- Manpower ramp-up in a project decides the milestones
- Manpower ramp-up in a project follows a Rayleigh curve - like a normal curve
- In reality manpower build-up is a step function

Manpower Ramp-up



Milestones …

- With manpower ramp-up and effort distribution, milestones can be decided
- Effort distribution and schedule distribution in phases are different
- Generally, the build has larger effort but not correspondingly large schedule
- COCOMO specifies distr of overall sched. Design – 19%, programming – 62%, integration – 18%

An Example Schedule

Task	Dur. (days)	Work (p-days)	Start Date	End Date
Project Init tasks	33	24	5/4	6/23
Training	95	49	5/8	9/29
Knowledge sharing	78	20	6/2	9/30
Elaboration iteration I	55	55	5/15	6/23
Construction iteration I	9	35	7/10	7/21

Detailed Scheduling

- To reach a milestone, many tasks have to be performed
- Lowest level tasks - those that can be done by a person (in less than 2-3 days)
- Scheduling - decide the tasks, assign them while preserving high-level schedule
- Is an iterative task - if cannot "fit" all tasks, must revisit high level schedule

Detailed Scheduling

- Detailed schedule not done completely in the start - it evolves
- Can use Microsoft Project for keeping it
- Detailed Schedule is the most live document for managing the project
- Any activity to be done must get reflected in the detailed schedule

An example task in detail schedule

Module	Act Code	Task	Duration	Effort
History	PUT	Unit test # 17	1 day	7 hrs
St. date	**End date**	**%comp**	**Depend.**	**Resource**
7/18	7/18	0%	Nil	SB

Detail schedule

- Each task has name, date, duration, resource etc assigned
- % done is for tracking (tools use it)
- The detailed schedule has to be consistent with milestones
  - Tasks are sub-activities of milestone level activities, so effort should add up, total schedule should be preserved

Quality Planning

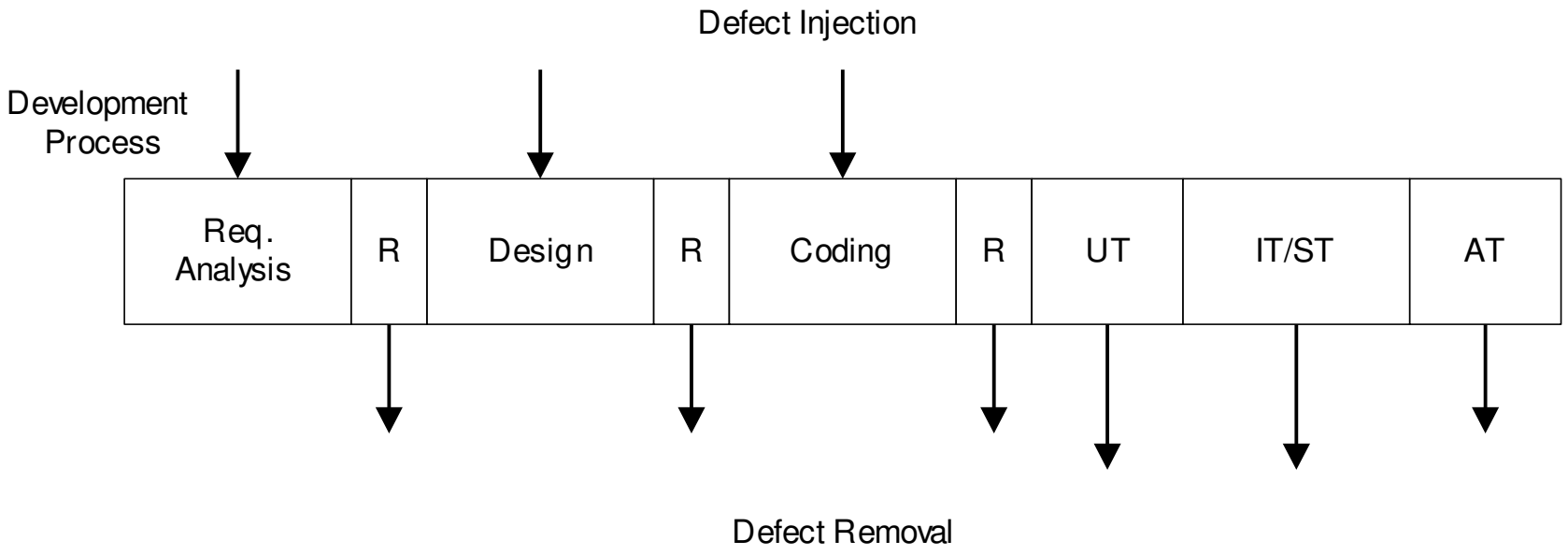
Quality Planning

- Delivering high quality is a basic goal
- Quality can be defined in many ways
- Current industry standard - *delivered defect density* (e.g. #defects/KLOC)
- Defect - something that causes software to behave in an inconsistent manner
- Aim of a project - deliver software with low delivered defect density

Defect Injection and Removal

- Software development is labor intensive
- Defects are injected at any stage
- As quality goal is low delivered defect density, these defects have to be removed
- Done primarily by quality control (QC) activities of reviews and testing

Defect Injection and Removal



Approaches to Quality Management

- Ad hoc - some testing, some reviews done as and when needed
- Procedural - defined procedures are followed in a project
- Quantitative - defect data analysis done to manage the quality process

Procedural Approach

- A quality plan defines what QC tasks will be undertaken and when
- Main QC tasks - reviews and testing
- Guidelines and procedures for reviews and testing are provided
- During project execution, adherence to the plan and procedures ensured

Quantitative Approach

- Goes beyond asking "has the procedure been executed"
- Analyzes defect data to make judgements about quality
- Past data is very important
- Key parameters - defect injection and removal rates, defect removal efficiency (DRE)

Quality Plan

- The quality plan drives the quality activities in the project
- Level of plan depends on models available
- Must define QC tasks that have to be performed in the project
- Can specify defect levels for each QC tasks (if models and data available)

Risk Management

Risk Management

- Any project can fail - reasons can be technical, managerial, etc.
- Project management aims to tackle the project management aspect
- Engineering life cycles aim to tackle the engineering issues
- A project may fail due to unforeseen events - risk management aims to tackle this

Risk Management

- Risk: any condition or event whose occurrence is not certain but which can cause the project to fail
- Aim of risk management: minimize the effect of risks on a project
- Risk management has two basic aspects
  - Risk assessment
  - Risk control

Risk Assessment

- To identify possible risks to a project, i.e. to those events that might occur and which might cause the project to fail
- No "algorithm" possible, done by "what ifs", checklists, past experience
- Can have a list of "top 10" risks that projects have seen in past

Top Risk Examples

- Shortage of technically trained manpower
- Too many requirement changes
- Unclear requirements
- Not meeting performance requirements
- Unrealistic schedules
- Insufficient business knowledge
- Working on new technology

Risk Prioritization

- The number of risks might be large
- Must prioritize them to focus attention on the "high risk" areas
- For prioritization, impact of each risk must be understood
- In addition, probability of the risk occurring should also be understood

Risk Prioritization …

- Risk exposure (RE) = probability of risk occurring * risk impact
- RE is the expected value of loss for a risk
- Prioritization can be done based on risk exposure value
- Plans can be made to handle high RE risks

A Simple approach to Risk Prioritization

- Classify risk occurrence probabilities as: Low, Medium, High
- Classify risk impact as: Low, Medium, High
- Identify those that are HH, or HM/MH
- Focus on these for risk mitigation
- Will work for most small and medium sized projects

Risk Control

- Can the risk be avoided?
  - E.g. if new hardware is a risk, it can be avoided by working with proven hardware
- For others, risk mitigation steps need to be planned and executed
  - Actions taken in the project such that if the risk materializes, its impact is minimal
  - Involves extra cost

Risk Mitigation Examples

- Too many requirement changes
  - Convince client that changes in requirements will have an impact on the schedule
  - Define a procedure for requirement changes
  - Maintain cumulative impact of changes and make it visible to client
  - Negotiate payment on actual effort.

Examples …

- Manpower attrition
  - Ensure that multiple resources are assigned on key project areas
  - Have team building sessions
  - Rotate jobs among team members
  - Keep backup resources in the project
  - Maintain documentation of individual's work
  - Follow the CM process and guidelines strictly

Examples ...

- Unrealistic schedules
  - Negotiate for better schedule
  - Identify parallel tasks
  - Have resources ready early
  - Identify areas that can be automated
  - If the critical path is not within the schedule, negotiate with the client
  - Negotiate payment on actual effort

Risk Mitigation Plan

- Risk mitigation involves steps that are to be performed (hence has extra cost)
- It is not a paper plan - these steps should be scheduled and executed
- These are different from the steps one would take if the risk materializes - they are performed only if needed
- Risks must be revisited periodically

A Practical Risk Mgmt Approach

- Based on methods of some orgs
  1. List risks; for each risk rate probability as Low, Medium, High
  2. For each risk assess impact on the project as Low, medium, High
  3. Rank the risks based on probability and impact – HH is the highest
  4. Select top few items for mitigation

A risk mgmt plan

Risk	Prob	Impact	Exposure
1. Failure to meet perf reqs	High	High	High
2. Lack of people with right skills	Med	Med	Med
3. Complexity of the application	Med	Med	Med
4. Unclear requirements	Med	Med	Med

Risk Mgmt plan…

Risk	Mitigation plan
1. Failure to meet perf reqs	Train team in perf engg Have perf testing scripts Use suitable tools
2. Lack of people with right skills	Train resources Develop suitable standards
3. Complexity of the application	Ensure ongoing k transfer Use people with domain exp
4. Unclear requirements	Have multiple reviews Build prototype

Project Monitoring Plans

Background

- A plan is a mere document that can guide
- It must be executed
- To ensure execution goes as per plan, it must be monitored and controlled
- Monitoring requires measurements
- And methods for interpreting them
- Monitoring plan has to plan for all the tasks related to monitoring

Measurements

- Must plan for measurements in a project
- Without planning, measurements will not be done
- Main measurements – effort, size, schedule, and defects
  - Effort – as this is the main resource; often tracked through effort reporting tools
  - Defects – as they determine quality; often defect logging and tracking systems used
- During planning – what will be measured, how, tool support, and data management

Project Tracking

- Goal: To get visibility in project execution so corrective actions can be taken when needed to ensure project succeeds
- Diff types of monitoring done at projects; measurements provide data for it

Tracking…

- Activity-level monitoring
  - Each activity in detailed schd is getting done
  - Often done daily by managers
  - A task done marked 100%; tools can determine status of higher level tasks
- Status reports
  - Generally done weekly to take stock
  - Summary of activities completed, pending
  - Issues to be resolved

Tracking...

- Milestone analysis
  - A bigger review at milestones
  - Actual vs estimated for effort and sched is done
  - Risks are revisited
  - Changes to product and their impact may be analyzed
- Cost-schedule milestone graph is another way of doing this

Project Management Plan

- The project management plan (PMP) contains outcome of all planning activities - focuses on overall project management
- Besides PMP, a project schedule is needed
  - Reflects what activities get done in the project
  - Microsoft project (MSP) can be used for this
  - Based on project planning; is essential for day-to-day management
  - Does not replace PMP !

PMP Structure - Example

- Project overview - customer, start and end date, overall effort, overall value, main contact persons, project milestones, development environment..
- Project planning - process and tailoring, requirements change mgmt, effort estimation, quality goals and plan, risk management plan, ..

PMP Example ...

- Project tracking - data collection, analysis frequency, escalation procedures, status reporting, customer complaints, ...
- Project team, its organization, roles and responsibility, ...

Project Planning - Summary

- Project planning forms the foundation of project management
- Key aspects: effort and schedule estimation, quality planning, risk mgmt., …
- Outputs of all can be documented in a PMP, which carries all relevant info about project
- Besides PMP, a detailed project schedule maintains tasks to be done in the project

Design

Software Design

- Design activity begins with a set of requirements, and maybe an architecture
- Design done before the system is implemented
- Design focuses on module view – i.e. what modules should be in the system
- Module view may have easy or complex relationship with the C&C view
- Design of a system is a blue print for implementation
- Often has two levels – high level (modules are defined), and detailed design (logic specified)

Design…

- Design is a creative activity
- Goal: to create a plan to satisfy requirements
- Perhaps the most critical activity during system development
- Design determines the major characteristics of a system
- Has great impact on testing and maintenance
- Design document forms reference for later phases
- Design methodology – systematic approach for creating a design

Design Concepts

- Design is correct, if it will satisfy all the requirements and is consistent with architecture
- Of the correct designs, we want *best design*
- We focus on modularity as the main criteria (besides correctness)

Modularity

- Modular system – in which modules can be built separately and changes in one have minimum impact on others
- Modularity supports independence of models
- Modularity enhances design clarity, eases implementation
- Reduces cost of testing, debugging and maintenance
- Cannot simply chop a program into modules to get modularly
- Need some criteria for decomposition – coupling and cohesion are such criteria

Coupling

- Independent modules: if one can function completely without the presence of other
- Independence between modules is desirable
  - Modules can be modified separately
  - Can be implemented and tested separately
  - Programming cost decreases
- In a system all modules cannot be independent
- Modules must cooperate with each other
- More connections between modules
  - More dependent they are
  - More knowledge about one module is required to understand the other module.
- Coupling captures the notion of dependence

Coupling…

- Coupling between modules is the strength of interconnections between modules
- In general, the more we must know about module A in order to understand module B the more closely connected is A to B
- "Highly coupled" modules are joined by strong interconnection
- "Loosely coupled" modules have weak interconnections

Coupling…

- Goal: modules as loosely coupled as possible
- Where possible, have independent modules
- Coupling is decided during high level design
- Cannot be reduced during implementation
- Coupling is inter-module concept
- Major factors influencing coupling
  - Type of connection between modules
  - Complexity of the interface
  - Type of information flow between modules

Coupling – Type of connection

- Complexity and obscurity of interfaces increase coupling
- Minimize the number of interfaces per module
- Minimize the complexity of each interface
- Coupling is minimized if
  - Only defined entry of a module is used by others
  - Information is passed exclusively through parameters
- Coupling increases if
  - Indirect and obscure interface are used
  - Internals of a module are directly used
  - Shared variables employed for communication

Coupling – interface complexity

- Coupling increases with complexity of interfaces eg. number and complexity of parms
- Interfaces are needed to support required communication
- Often more than needed is used eg. passing entire record when only a field is needed
- Keep the interface of a module as simple as possible

Coupling – Type of Info flow

- Coupling depends on type of information flow
- Two kinds of information: data or control.
- Transfer of control information
  - Action of module depends on the information
  - Makes modules more difficult to understand
- Transfer of data information
  - Module can be treated as input-output function
- Lowest coupling: interfaces with only data communication
- Highest: hybrid interfaces

Coupling - Summary

Coupling	Interface complexity	Type of connections	Type of commu-nication
Low	Simple obvious	to module by name	data
High	complicated obscure	to internal elements	Hybrid

Coupling in OO Systems

- In OO systems, basic modules are classes, which are richer than fns
- OO Systems have three types of coupling
  - Interaction coupling
  - Component coupling
  - Inheritance coupling

Coupling in OO - Interaction

- Interaction coupling occurs due to methods of a class invoking methods of other classes
  - Like calling of functions
  - Worst form if methods directly access internal parts of other methods
  - Still bad if methods directly manipulate variables of other classes
  - Passing info through tmp vars is also bad

Coupling in OO …

- Least interaction coupling if methods communicate directly with parameters
  - With least number of parameters
  - With least amount of info being passed
  - With only data being passed
- I.e. methods should pass the least amount of data, with least no of parms

Coupling in OO - Component

- Component coupling – when a class A has variables of another class C
  - A has instance vars of C
  - A has some parms of type C
  - A has a method with a local var of type C
- When A is coupled with C, it is coupled with all subclasses of C as well
- Component coupling will generally imply the presence of interaction coupling also

Coupling in OO - Inheritance

- Inheritance coupling – two classes are coupled if one is a subclass of other
- Worst form – when subclass modifies a signature of a method or deletes a method
- Coupling is bad even when same signature but a changed implementation
- Least, when subclass only adds instance vars and methods but does not modify any

Cohesion

- Coupling characterized the inter-module bond
- Reduced by minimizing relationship between elts of different modules
- Another method of achieving this is by maximizing relationship between elts of same module
- Cohesion considers this relationship
- Interested in determining how closely the elements of a module are related to each other
- In practice both are used

Cohesion…

- Cohesion of a module represents how tightly bound are the elements of the module
- Gives a handle about whether the different elements of a module belong together
- High cohesion is the goal
- Cohesion and coupling are interrelated
- Greater cohesion of modules, lower coupling between module
- Correlation is not perfect.

Levels of Cohesion

- There are many levels of cohesion.
  - Coincidental
  - Logical
  - Temporal
  - Communicational
  - Sequential
  - Functional
- Coincidental is lowest, functional is highest
- Scale is not linear
- Functional is considered very strong

Determining Cohesion

- Describe the purpose of a module in a sentence
- Perform the following tests

1. If the sentence has to be a compound sentence, contains more than one verbs, the module is probably performing more than one function. Probably has sequential or communicational cohesion.
2. If the sentence contains words relating to time, like "first", "next", "after", "start" etc., the module probably has sequential or temporal cohesion.

3. If the predicate of the sentence does not contain a single specific object following the verb, the module is probably logically cohesive. Eg "edit all data", while "edit source data" may have functional cohesion.

4. Words like "initialize", "clean-up" often imply temporal cohesion.

- Functionally cohesive module can always be described by a simple statement

Cohesion in OO Systems

- In OO, different types of cohesion is possible as classes are the modules
  - Method cohesion
  - Class cohesion
  - Inheritance cohesion
- Method cohesion – why diff code elts are together in a method
  - Like cohesion in functional modules; highest form is if each method implements a clearly defined function with all elts contributing to implementing this function

Cohesion in OO...

- Class cohesion – why diff attributes and methods are together in a class
  - A class should represent a single concept with all elts contributing towards it
  - Whenever multiple concepts encapsulated, cohesion is not as high
  - A symptom of multiple concepts – diff gps of methods accessing diff subsets of attributes

Cohesion in OO...

- Inheritance cohesion – focuses on why classes are together in a hierarchy
  - Two reasons for subclassing – generalization-specialization and reuse
  - Cohesion is higher if the hierarchy is for providing generalization-specialization

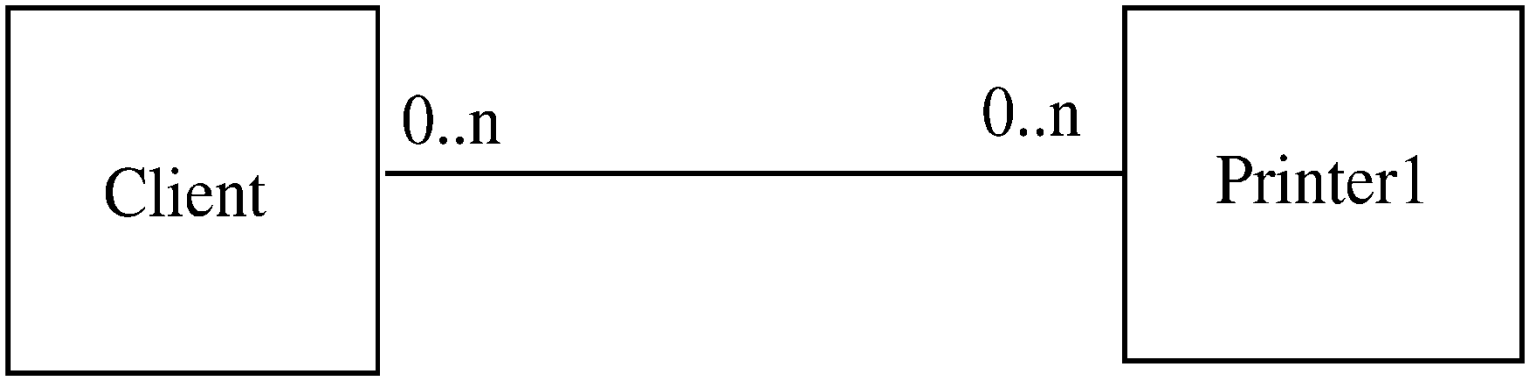
Open-closed Principle

- Besides cohesion and coupling, open closed principle also helps in achieving modularity
- Principle: A module should be open for extension but closed for modification
  - Behavior can be extended to accommodate new requirements, but existing code is not modified
  - I.e. allows addition of code, but not modification of existing code
  - Minimizes risk of having existing functionality stop working due to changes – a very important consideration while changing code
  - Good for programmers as they like writing new code

Open-closed Principle…

- In OO this principle is satisfied by using inheritance and polymorphism
- Inheritance allows creating a new class to extend behavior without changing the original class
- This can be used to support the open-closed principle
- Consider example of a client object which interacts with a printer object for printing

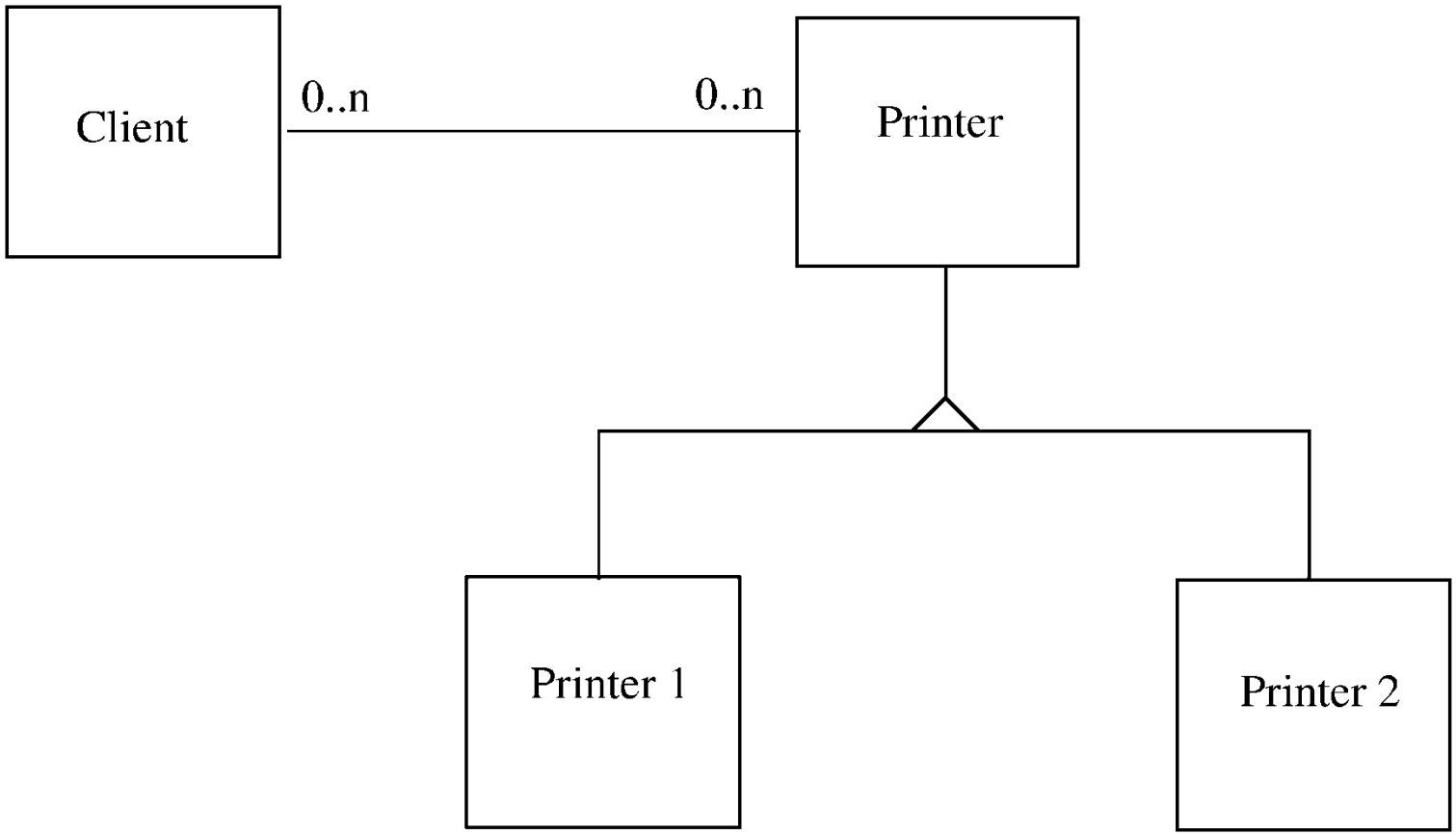
Example



Example..

- Client directly calls methods on Printer1
- If another printer is to be allowed
  - A new class Printer2 will be created
  - But the client will have to be changed if it wants to use Printer 2
- Alternative approach
  - Have Printer1 a subclass of a general Printer
  - For modification, add another subclass Printer 2
  - Client does not need to be changed

Example...



Liskov's Substitution Principle

- Principle: Program using object o1 of base class C should remain unchanged if o1 is replaced by an object of a subclass of C
- If hierarchies follow this principle, the open-closed principle gets supported

Summary

- Goal of designing is to find the best possible correct design
- Modularity is the criteria for deciding quality of the design
- Modularity enhanced by low coupling, high cohesion, and following open-closed principle

Function Oriented Design and Structured Design Methodology

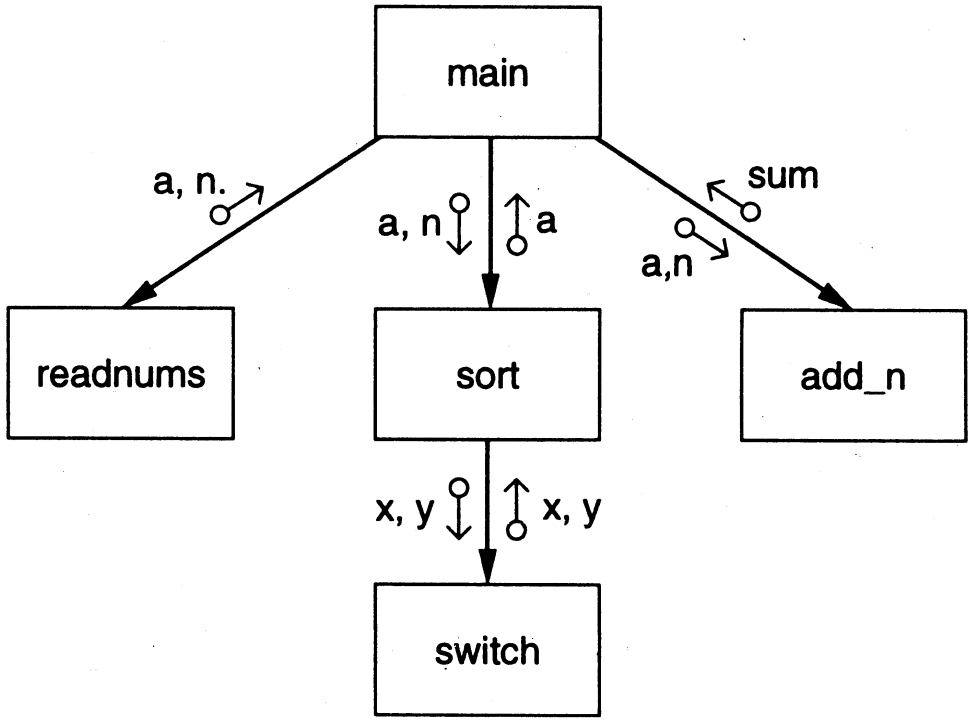
Program Structure and Structure Charts

- Every program has a structure
- Structure Chart - graphic representation of structure
- SC represents modules and interconnections
- Each module is represented by a box
- If A invokes B, an arrow is drawn from A to B
- Arrows are labeled by data items
- Different types of modules in a SC
- Input, output, transform and coordinate modules
- A module may be a composite

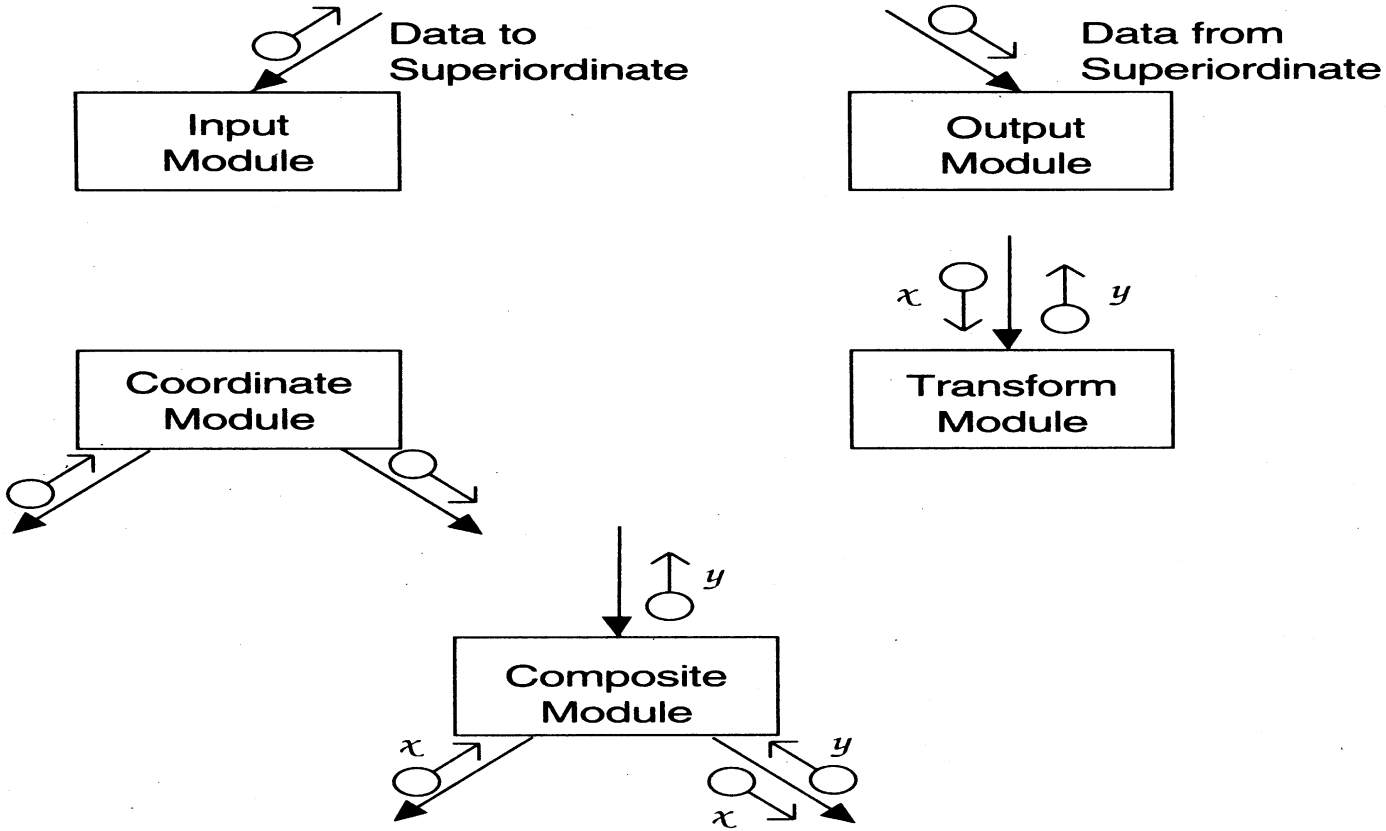
Structure charts...

- SC shows the static structure, not the logic
- Different from flow charts
- Major decisions and loops can be shown
- Structure is decided during design
- Implementation does not change structure
- Structure effects maintainability
- SDM aims to control the structure

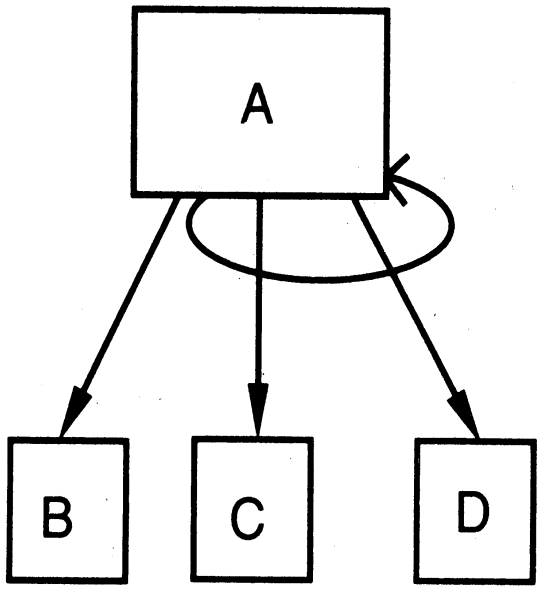
SC of a Sort Program

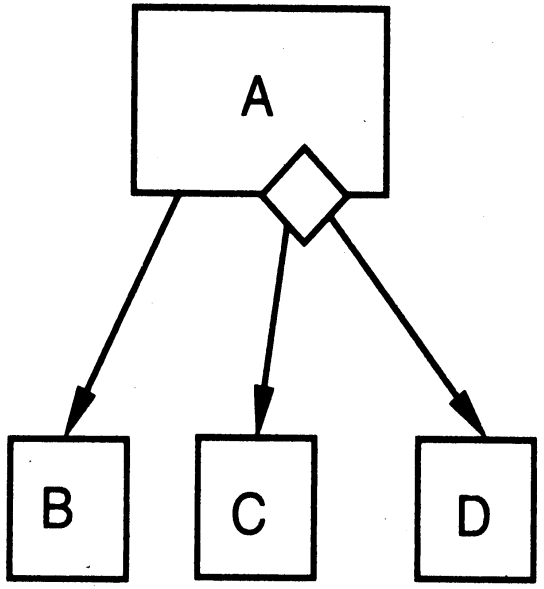


Diff types of modules



Iteration and decision





STRUCTURED DESIGN METHODOLOGY

- SDM views software as a transformation function that converts given inputs to desired outputs
- The focus of SD is the transformation function
- Uses functional abstraction
- Goal of SDM: Specify functional modules and connections
- Low coupling and high cohesion is the objective

Steps in SD

1. Draw a DFD of the system
2. Identify most abstract inputs and most abstract outputs
3. First level factoring
4. Factoring of input, output, transform modules
5. Improving the structure

1. Data Flow Diagrams

- SD starts with a DFD to capture flow of data in the proposed system
- DFD is an important representation; provides a high level view of the system
- Emphasizes the flow of data through the system
- Ignores procedural aspects
- (Purpose here is different from DFDs used in requirements analysis, thought notation is the same)

Drawing a DFG

- Start with identifying the inputs and outputs
- Work your way from inputs to outputs, or vice versa
  - If stuck, reverse direction
  - Ask: "What transformations will convert the inputs to outputs"
- Never try to show control logic.
  - If thinking about loops, if-then-else, start again
- Label each arrow carefully
- Make use of * and +, and show sufficient detail
- Ignore minor functions in the start
- For complex systems, make dfg hierarchical
- Never settle for the 1st dfg

Step 2 of SD Methodology

- Generally a system performs a basic function
- Often cannot be performed on inputs directly
- First inputs must be converted into a suitable form
- Similarly for outputs - the outputs produced
- by main transforms need further processing
- Many transforms needed for processing inputs and outputs
- Goal of step 2 is to separate such transforms from the basic transform centers

Step 2...

- Most abstract inputs: data elements in dfg that are furthest from the actual inputs, but can still be considered as incoming
- These are logical data items for the transformation
- May have little similarity with actual inputs.
- Often data items obtained after error checking, formatting, data validation, conversion etc.

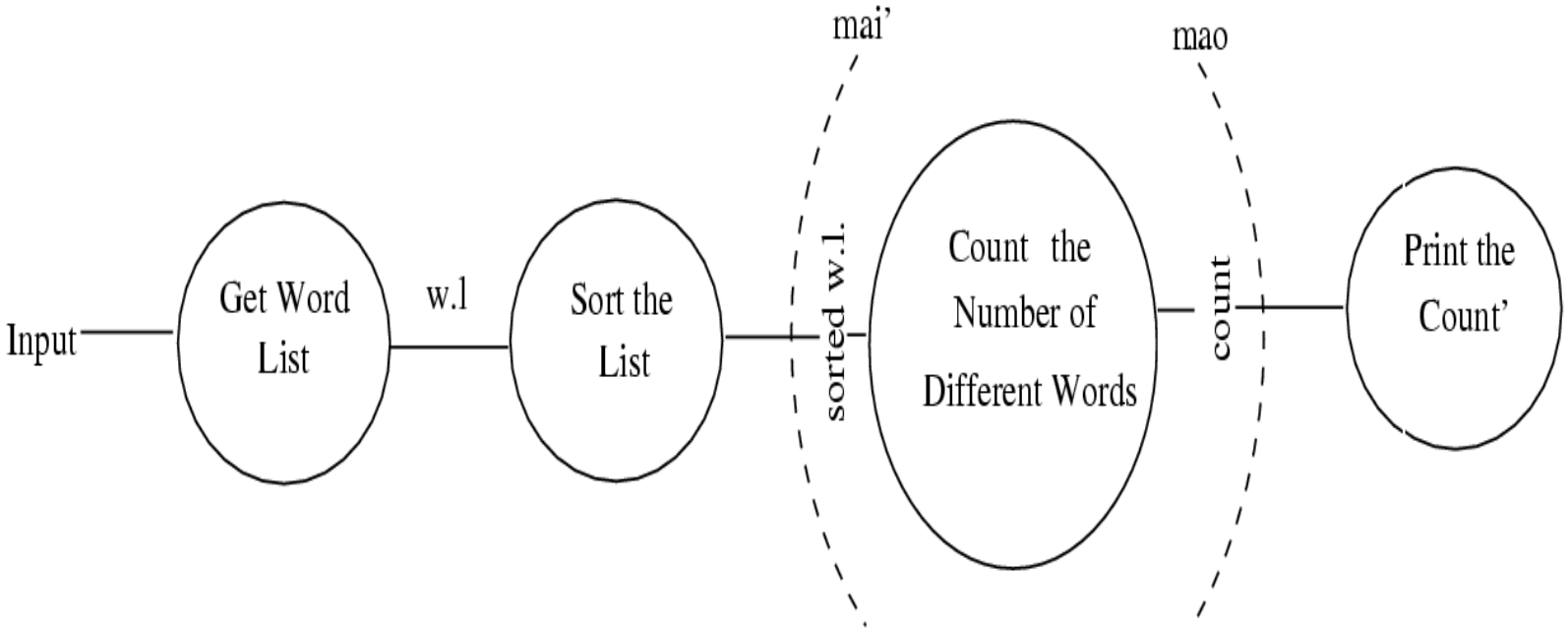
Step 2...

- Travel from physical inputs towards outputs until data can no longer be considered incoming
- Go as far as possible, without loosing the incoming nature
- Similarly for most abstract outputs
- Represents a value judgment, but choice is often obvious
- Bubbles between mai and mao: central transforms
- These transforms perform the basic transformation
- With mai and mao the central transforms can concentrate on the transformation

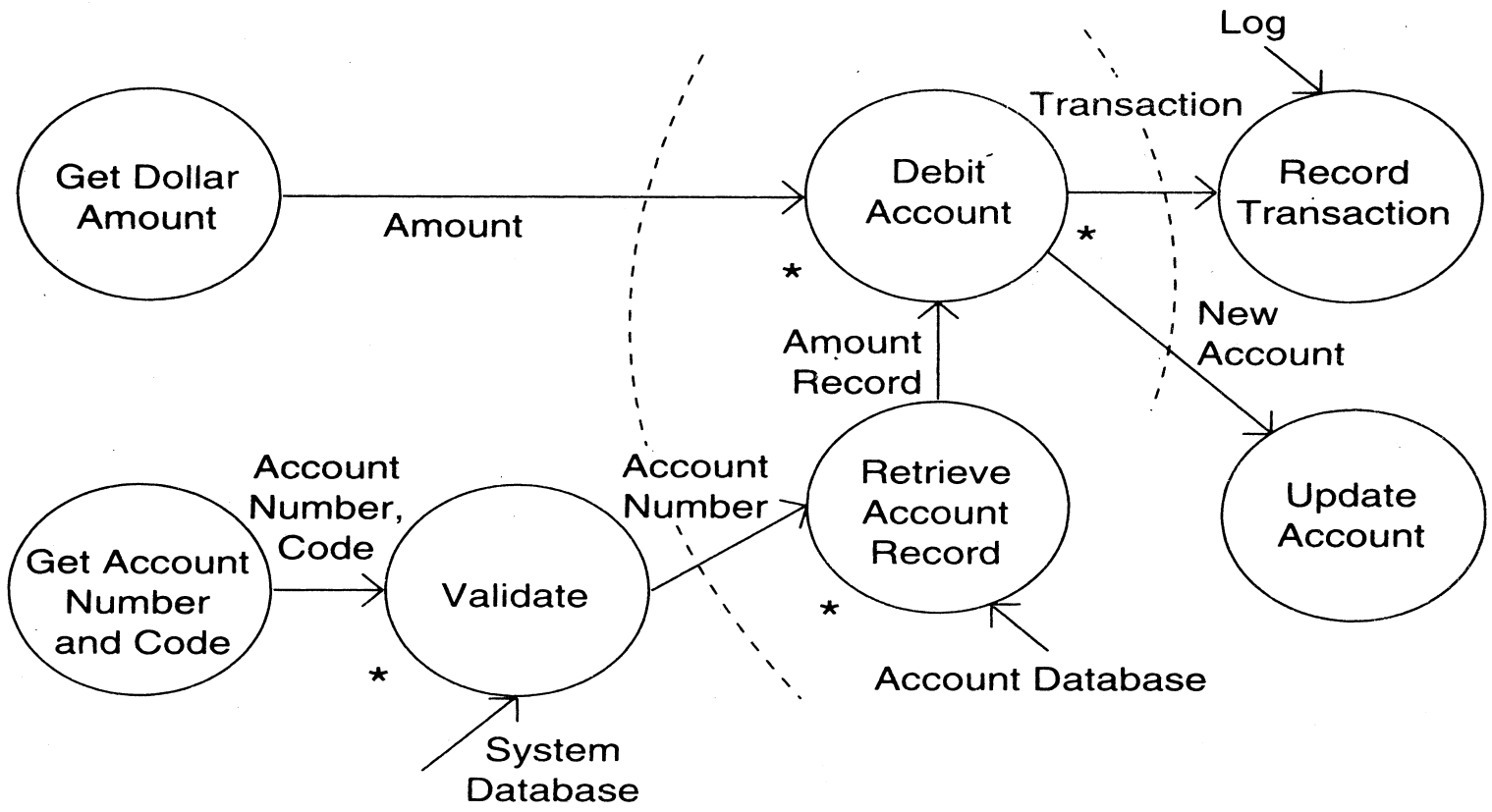
Step 2...

- Problem View: Each system does some i/o and some processing
- In many systems the i/o processing forms the large part of the code
- This approach separates the different functions
  - subsystem primarily performing input
  - subsystem primarily performing transformations
  - subsystem primarily performing output presentation

no of different words in a file



Example 2 – ATM

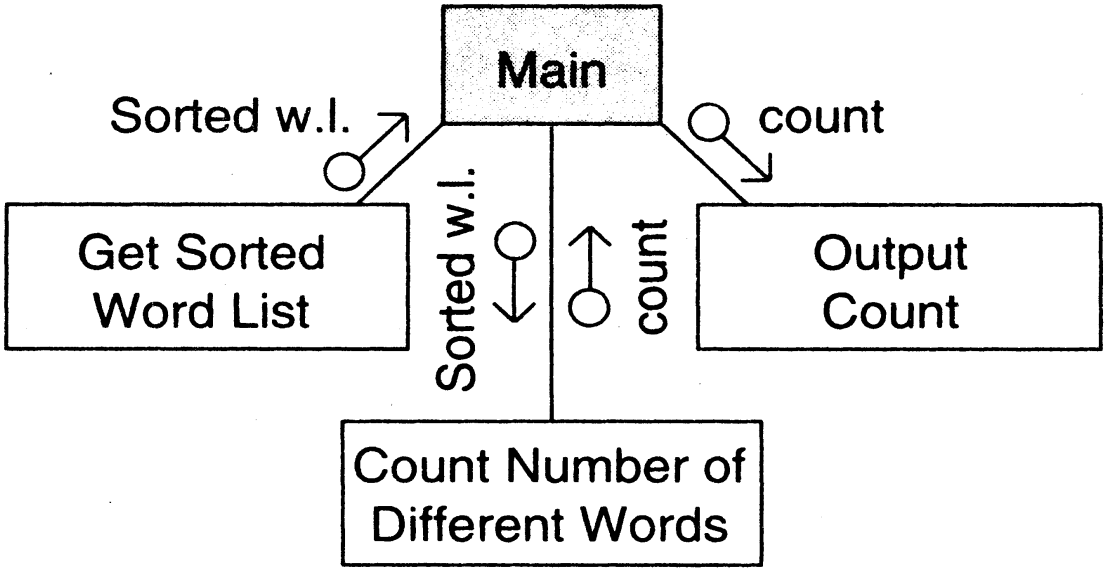


3. First Level Factoring

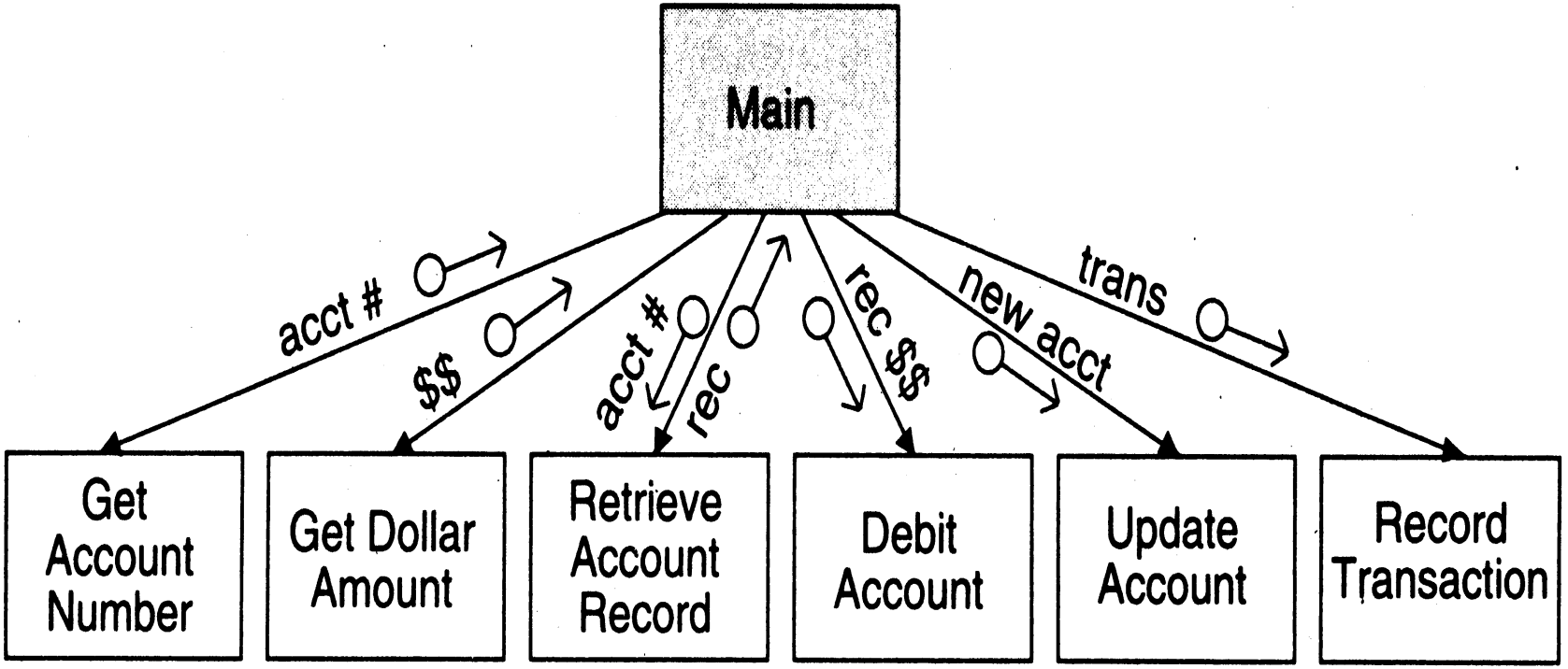
- First step towards a structure chart
- Specify a main module
- For each most abstract input data item, specify a subordinate input module
- The purpose of these input modules is to deliver to main the mai data items
- For each most abstract output data element, specify an output module
- For each central transform, specify a subordinate transform module
- Inputs and outputs of these transform modules are specified in the DFD

- First level factoring is straight forward
- Main module is a coordinate module
- Some subordinates are responsible for delivering the logical inputs
- These are passed to transform modules to get them converted to logical outputs
- Output modules then consume them
- Divided the problem into three separate problems
- Each of the three diff. types of modules can be designed separately
- These modules are independent

Example 1


Main
Sorted w.l.
count
Get Sorted
Word List
Sorted w.l.
count
Output
Count
Count Number of
Different Words

Example 2

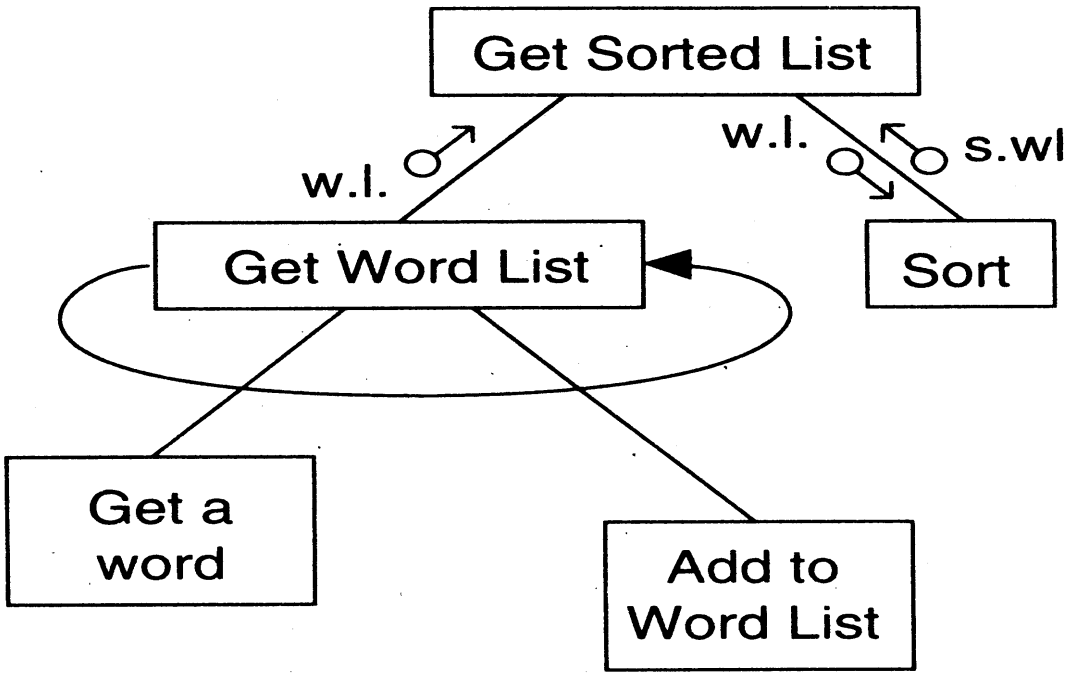

Main
acct #
$$
acct #
rec
rec $$
new acct
trans
Get Account Number
Get Dollar Amount
Retrieve Account Record
Debit Account
Update Account
Record Transaction

4. Factoring Input modules

- The transform that produced the mai data is treated as the central transform
- Then repeat the process of first level factoring
- Input module being factored becomes the main module
- A subordinate input module is created for each data item coming in this new central transform
- A subordinate module is created for the new central transform
- Generally there will be no output modules

- The new input modules are factored similarly Till the physical inputs are reached
- Factoring of the output modules is symmetrical
- Subordinates - a transform and output modules
- Usually no input modules

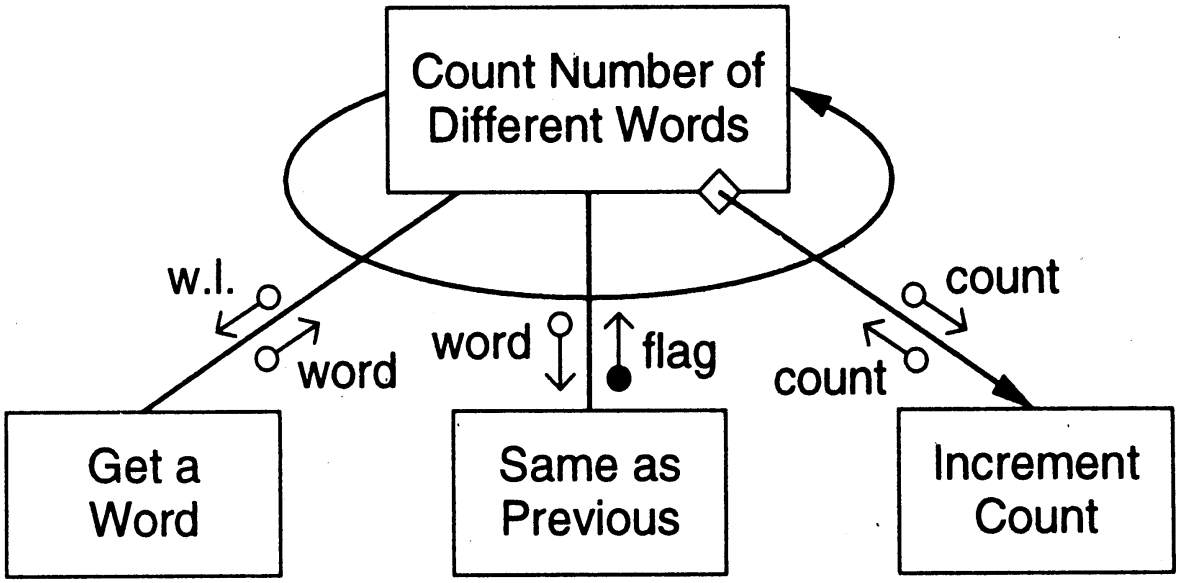
Example 1


Get Sorted List
w.l.
w.l.
s.wl
Get Word List
Sort
Get a word
Add to Word List

Factoring Central Transforms

- Factoring i/o modules is straight forward if the DFD is detailed
- No rules for factoring the transform modules
- Top-down refinement process can be used
- Goal: determine sub-transforms that will together compose the transform
- Then repeat the process for newly found transforms
- Treat the transform as a problem in its own right
- Draw a data flow graph
- Then repeat the process of factoring
- Repeat this till atomic modules are reached

Example 1


Count Number of Different Words
w.l.
word
word
flag
count
count
Get a Word
Same as Previous
Increment Count

5. Improving Design through Heuristics

- The above steps should not be followed blindly
- The structure obtained should be modified if needed
- Low coupling, high cohesion being the goal
- Design heuristics used to modify the initial design
- Design heuristics - A set of thumb rules that are generally useful
- Module Size: Indication of module complexity
  Carefully examine modules less than a few lines or greater than about 100 lines
- Fan out and fan in
- A high fan out is not desired, should not be increased beyond 5 or 6
- Fan in should be maximized

- Scope of effect of a module: the modules affected by a decision inside the module
- Scope of control: All subordinates of the module
- Good thumb rule:

  For each module scope of effect should be a subset of scope of control
- Ideally a decision should only effect immediate subordinates
- Moving up the decision, moving the module down can be utilized to achieve this

Summary

- Structured design methodology is one way to create modular design
- It partitions the system into input subsystems, output subsystems & transform subsystems
- Idea: Many systems use a lot of code for handling inputs & outputs
- SDM separates these concerns
- Then each of the subsystems is factored using the DFD
- The design is finally documented & verified before proceeding

Object Oriented Design and UML

OO Concepts

OO Concepts

- Information hiding – use encapsulation to restrict external visibility
- OO encapsulates the data, provides limited access, visibility
- Info hiding can be provided without OO – is an old concept

OO Concepts…

- State retention – fns, procedures do not retain state; an object is aware of its past and maintains state
- Identity – each object can be identified and treated as a distinct entity
- Behavior – state and services together define the behavior of an object, or how an object responds

OO Concepts..

- Messages – through which a sender obj conveys to a target obj a request
- For requesting O1 must have – a handle for O2, name of the op, info on ops that O2 requires
- General format O2.method(args)

OO Concepts..

- Classes – a class is a stencil from which objects are created; defines the structure and services. A class has
  - An interface which defines which parts of an object can be accessed from outside
  - Body that implements the operations
  - Instance variables to hold object state
- Objects and classes are different; class is a type, object is an instance
- State and identity is of objects

Relationship among objects

- An object has some capability – for other services it interacts with other objects
- Some different ways for interaction:
  1. Supplier object is global to client
  2. Supplier obj is a parm to some op of the client
  3. Supplier obj is part of the client obj
  4. Supplier obj is locally declared in some op
- Relationship can be either aggregation (whole-part relationship), or just client server relationship

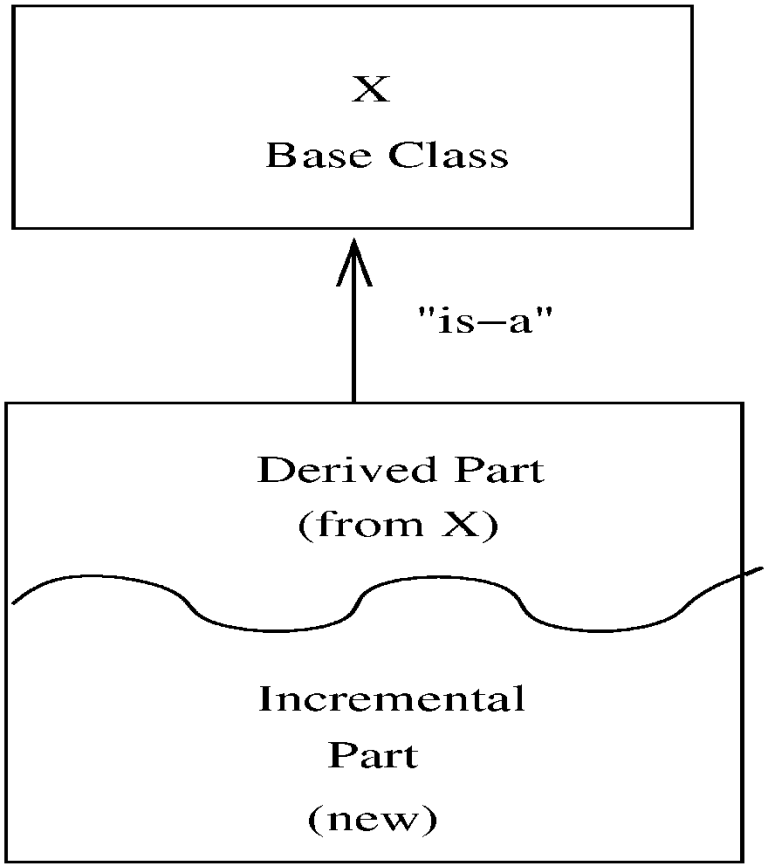
Inheritance

- Inheritance is unique to OO and not there in function-oriented languages/models
- Inheritance by class B from class A is the facility by which B implicitly gets the attributes and ops of A as part of itself
- Attributes and methods of A are reused by B
- When B inherits from A, B is the *subclass* or *derived* class and A is the *base* class or *superclass*

Inheritance..

- A subclass B generally has a derived part (inherited from A) and an incremental part (is new)
- Hence, B needs to define only the incremental part
- Creates an “is-a” relationship – objects of type B are also objects of type A

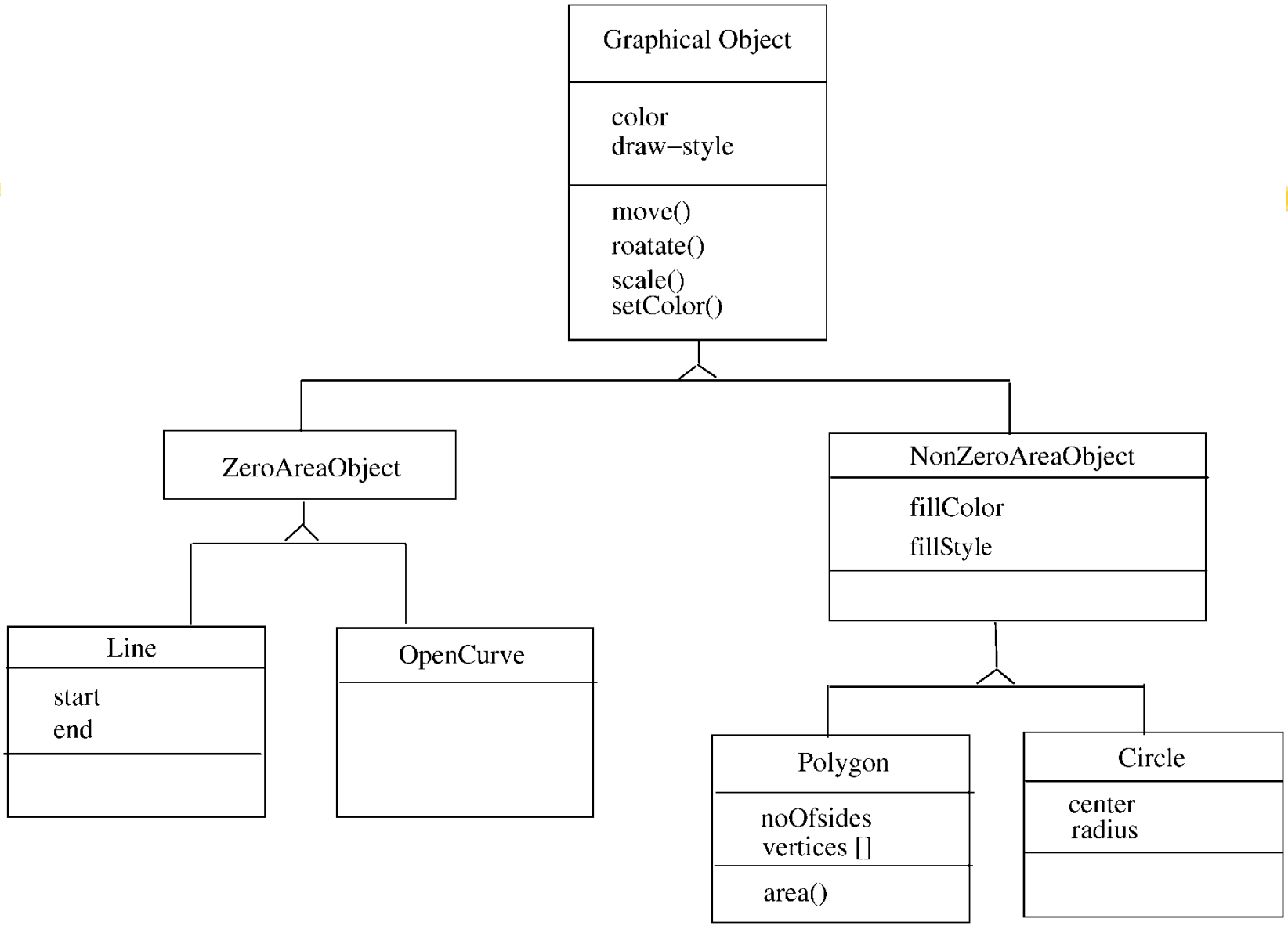
Inheritance...



Y – Derived class

Inheritance…

- The inheritance relationship between classes forms a class hierarchy
- In models, hierarchy should represent the natural relationships present in the problem domain
- In a hierarchy, all the common features can be accumulated in a superclass
- An existing class can be a specialization of an existing general class – is also called generalization-specialization relationships


Graphical Object
color
draw–style
move()
roatate()
scale()
setColor()
ZeroAreaObject
NonZeroAreaObject
fillColor
fillStyle
Line
start
end
OpenCurve
Polygon
noOfsides
vertices []
area()
Circle
center
radius

Inheritance…

- Strict inheritance – a subclass takes all features of parent class
- Only adds features to specialize it
- Non-strict: when some of the features have been redefined
- Strict inheritance supports “is-a” cleanly and has fewer side effects

Inheritance…

- Single inheritance – a subclass inherits from only one superclass
  - Class hierarchy is a tree
- Multiple inheritance – a class inherits from more than one class
  - Can cause runtime conflicts
  - Repeated inheritance - a class inherits from a class but from two separate paths

Inheritance and Polymorphism

- Inheritance brings polymorphism, i.e. an object can be of different types
- An object of type B is also an object of type A
- Hence an object has a static type and a dynamic type
  - Implications on type checking
  - Also brings dynamic binding of operations which allows writing of general code where operations do different things depending on the type

Unified Modeling Language (UML) and Modeling

- UML is a graphical notation useful for OO analysis and design
- Allows representing various aspects of the system
- Various notations are used to build different models for the system
- OOAD methodologies use UML to represent the models they create

Modeling

- Modeling is used in many disciplines – architecture, aircraft building, …
- A model is a simplification of reality
- "All models are wrong, some are useful"
- A good model includes those elts that have broad effect and omits minor elts
- A model of a system is not the system!

Why build models?

- Models help us visualize a system
- Help specify the system structure
- Gives us a template that can guide the construction
- Document the decisions taken and their rationale

Modeling

- Every complex system requires multiple models, representing diff aspects
- These models are related but can be studied in isolation
- Eg. Arch view, electrical view, plumbing view of a building
- Model can be structural, or behavioral

Views in an UML

- A use case view
- A design view
- A process view
- Implementation view
- Deployment view

- We will focus primarily on models for design – class diagram, interaction diagram, etc.

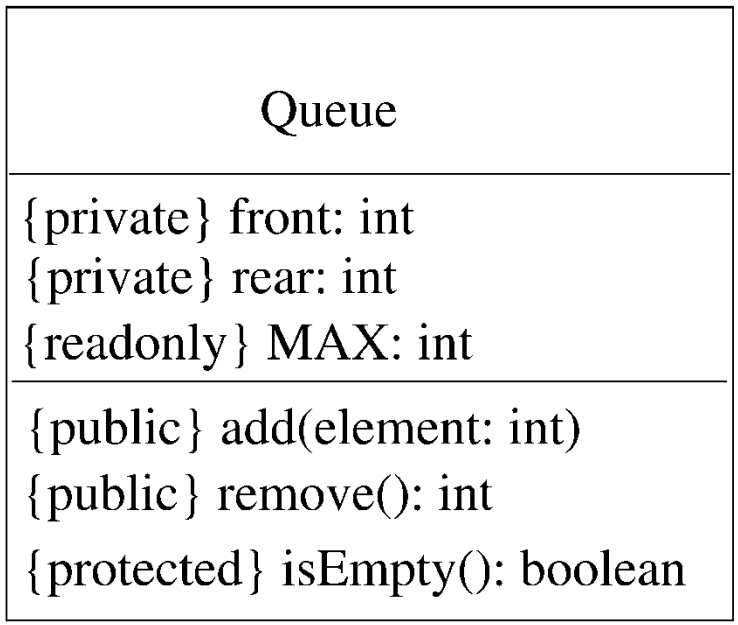
Class Diagrams

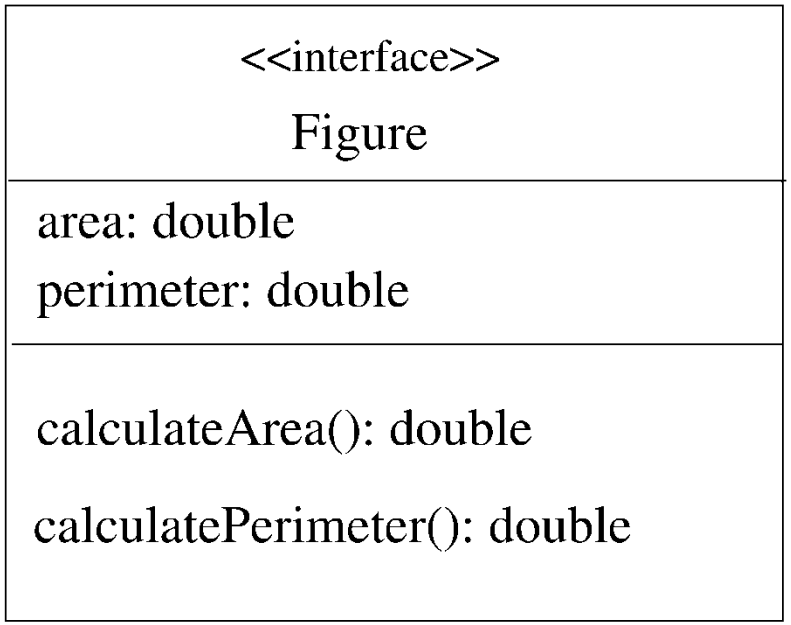
- Classes are the basic building blocks of an OO system as classes are the implementation units also
- Class diagram is the central piece in an OO design. It specifies
  - Classes in the system
  - Association between classes
  - Subtype, supertype relationship

Class Diagram…

- Class itself represented as a box with name, attributes, and methods
- There are conventions for naming
- If a class is an interface, this can be specified by <<interface>> stereotype
- Properties of attr/methods can be specified by tags between { }

Class – example

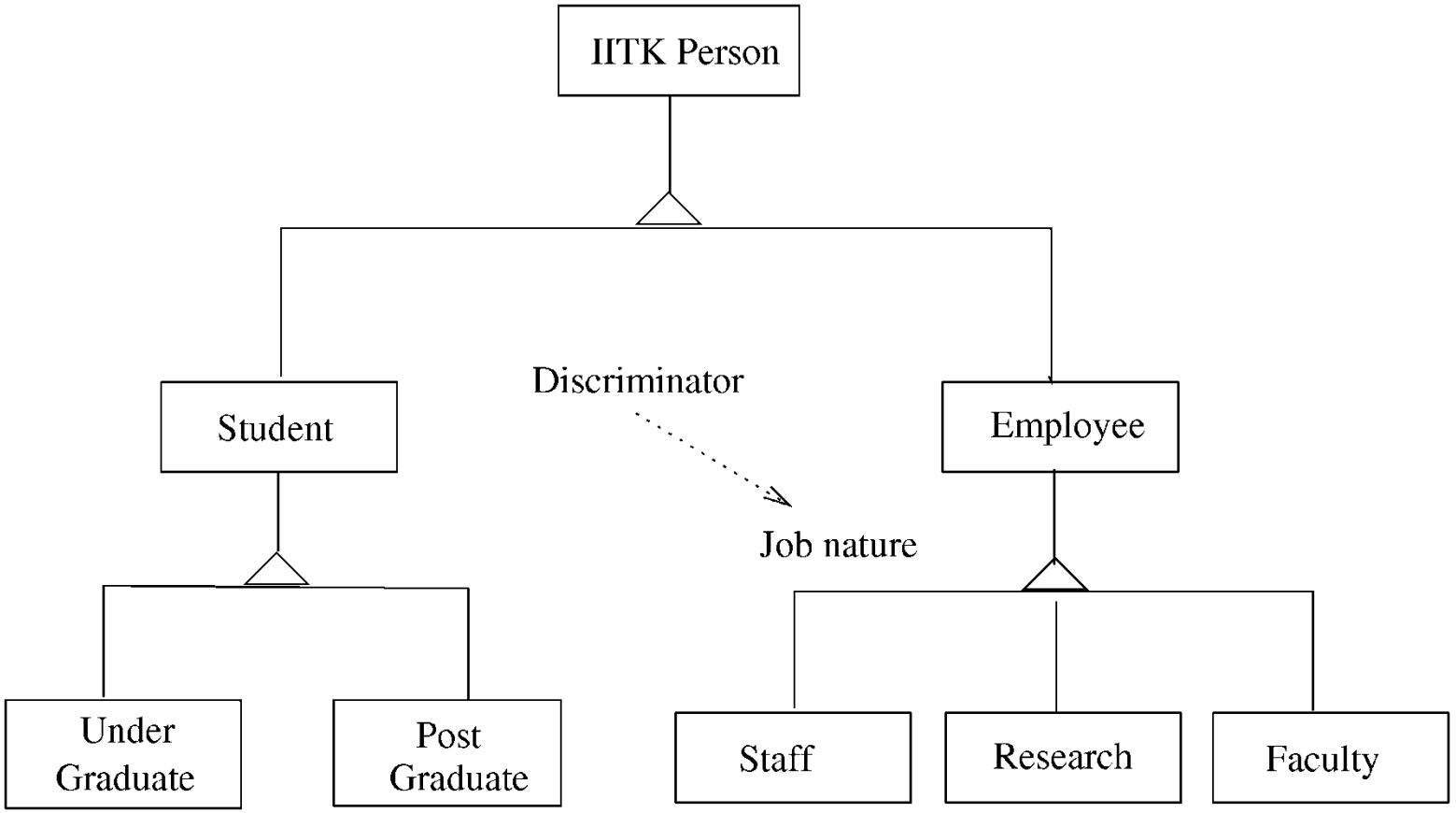




Generalization-Specialization

- This relationship leads to class hierarchy
- Can be captured in a class diagram
  - Arrows coming from the subclass to the superclass with head touching super
  - Allows multiple subclasses
  - If specialization is done on the basis of some discriminator, arrow can be labeled

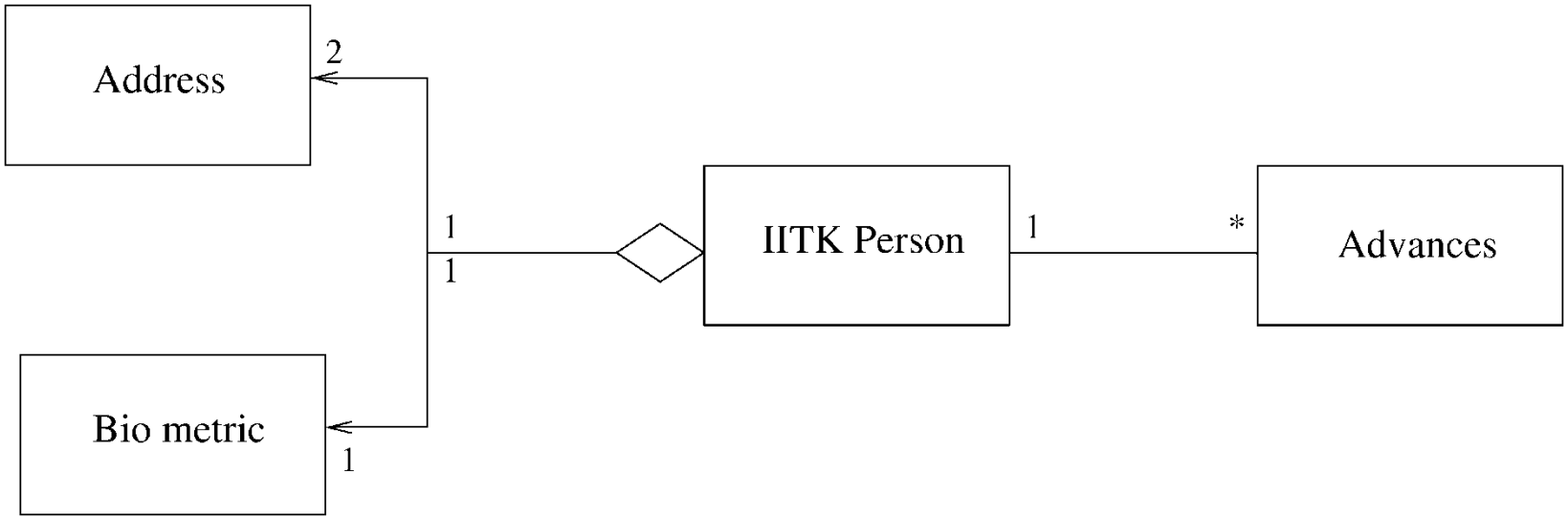
Example – class hierarchy



Association/aggregation

- Classes have other relationships
- Association: when objects of a class need services from other objects
  - Shown by a line joining classes
  - Multiplicity can be represented
- Aggregation: when an object is composed of other objects
  - Captures part-whole relationship
  - Shown with a diamond connecting classes

Example – association/aggregation



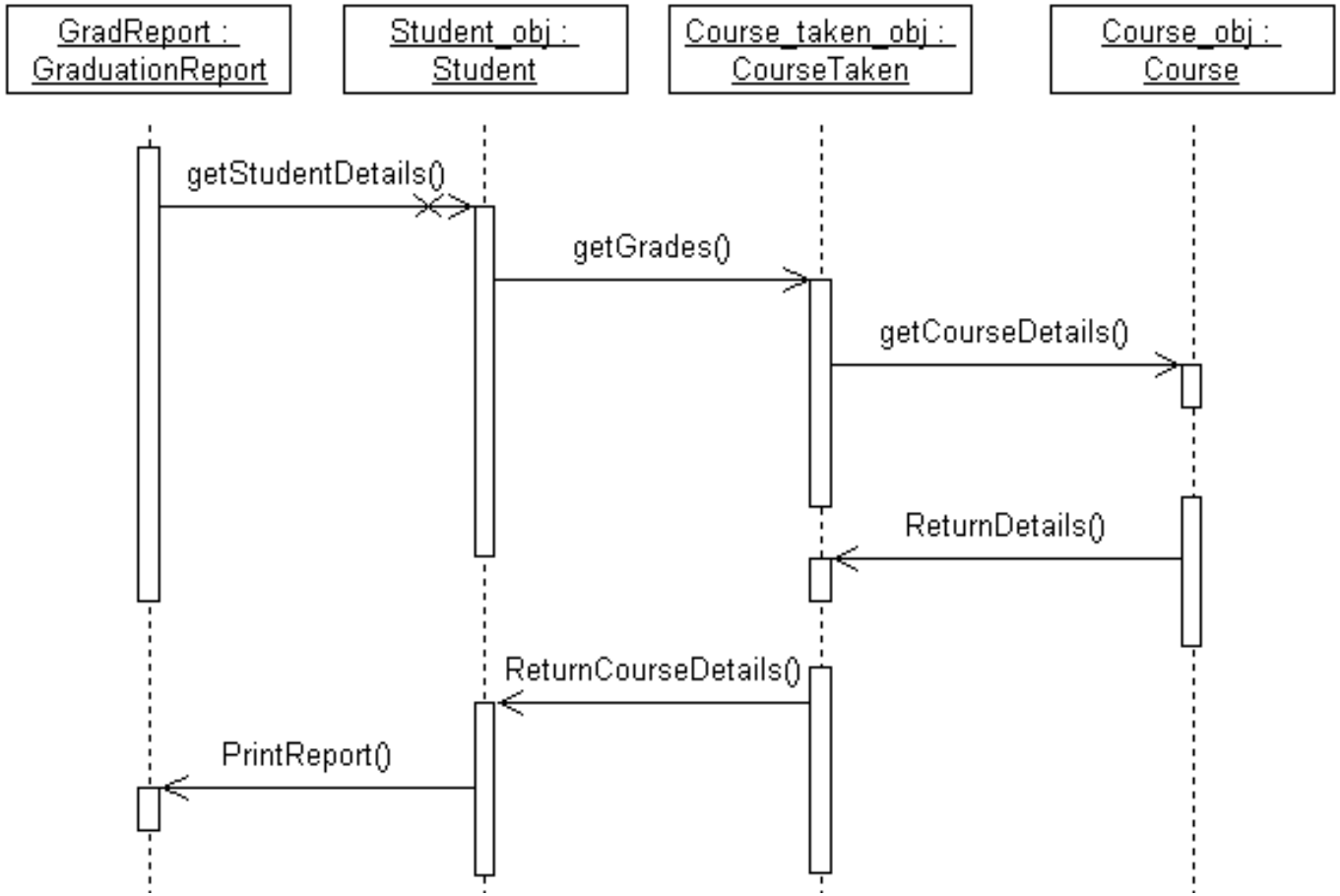
Interaction Diagrams

- Class diagram represent static structure of the system (classes and their rel)
- Do not model the behavior of system
- Behavioral view – shows how objects interact for performing actions (typically a use case)
- Interaction is between objects, not classes
- Interaction diagram in two styles
  - Collaboration diagram
  - Sequence diagram
- Two are equivalent in power

Sequence Diagram

- Objects participating in an interaction are shown at the top
- For each object a vertical bar represents its lifeline
- Message from an object to another, represented as a labeled arrow
- If message sent under some condition, it can be specified in bracket
- Time increases downwards, ordering of events is captured

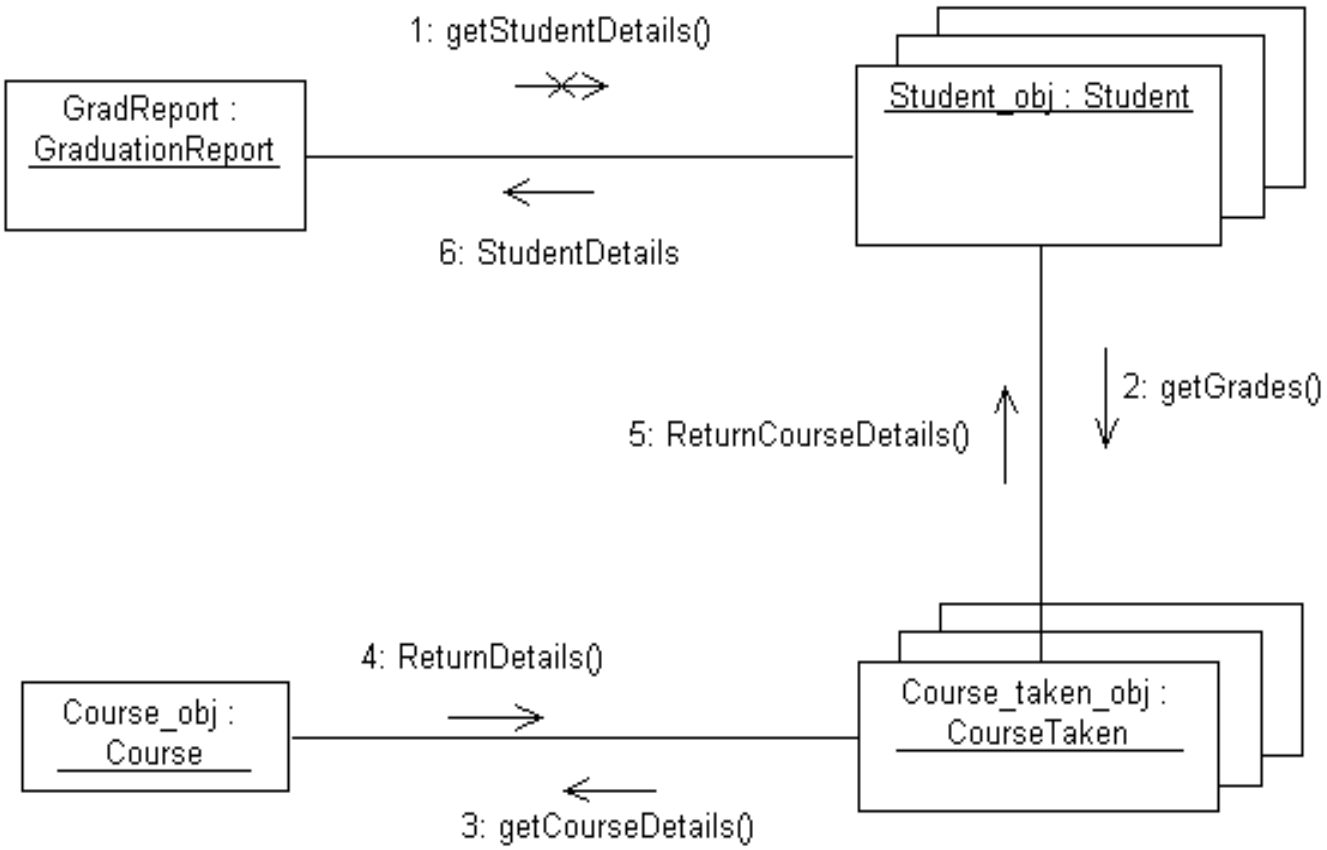
Example – sequence diag.



Collaboration diagram

- Also shows how objects interact
- Instead of timeline, this diagram looks more like a state diagram
- Ordering of messages captured by numbering them
- Is equivalent to sequence diagram in modeling power

Example – collaboration diag



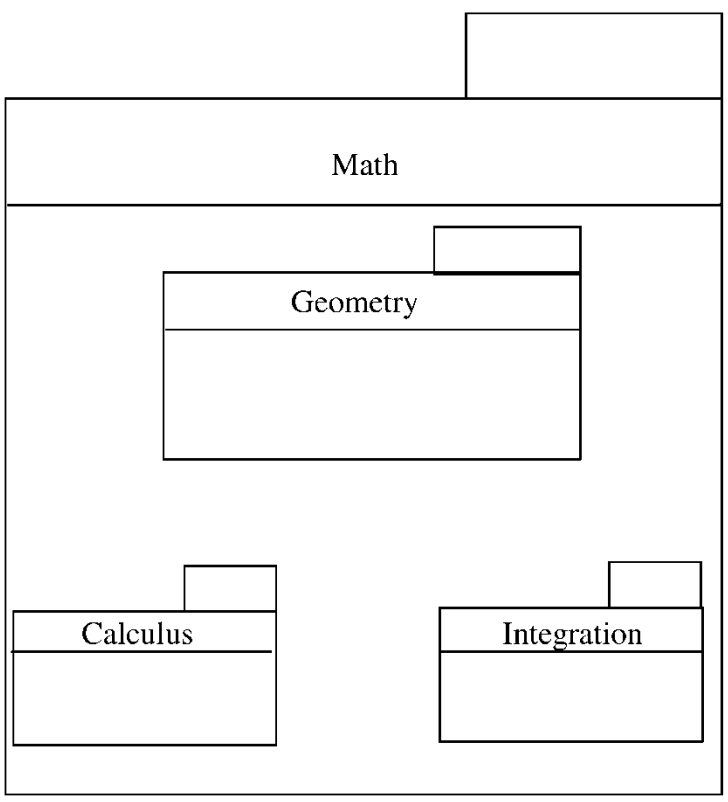
Other Diagrams

- Class diagram and interaction diagrams most commonly used during design
- There are other diagrams used to build different types of models

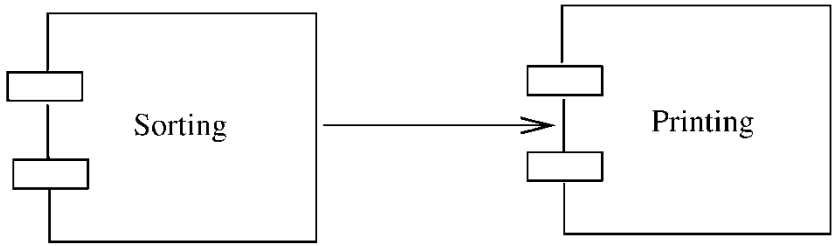
Other Diagrams

- Instead of objects/classes, can represent components, packages, subsystems
- These are useful for developing architecture structures
- UML is extensible – can model a new but similar concept by using stereotypes (by adding <<name>>)
- Tagged values can be used to specify additional properties, e.g. private, readonly..
- Notes can be added

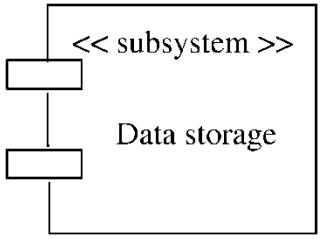
Other symbols



PACKAGE



COMPONENT – CONNECTOR



SUBSYSTEM

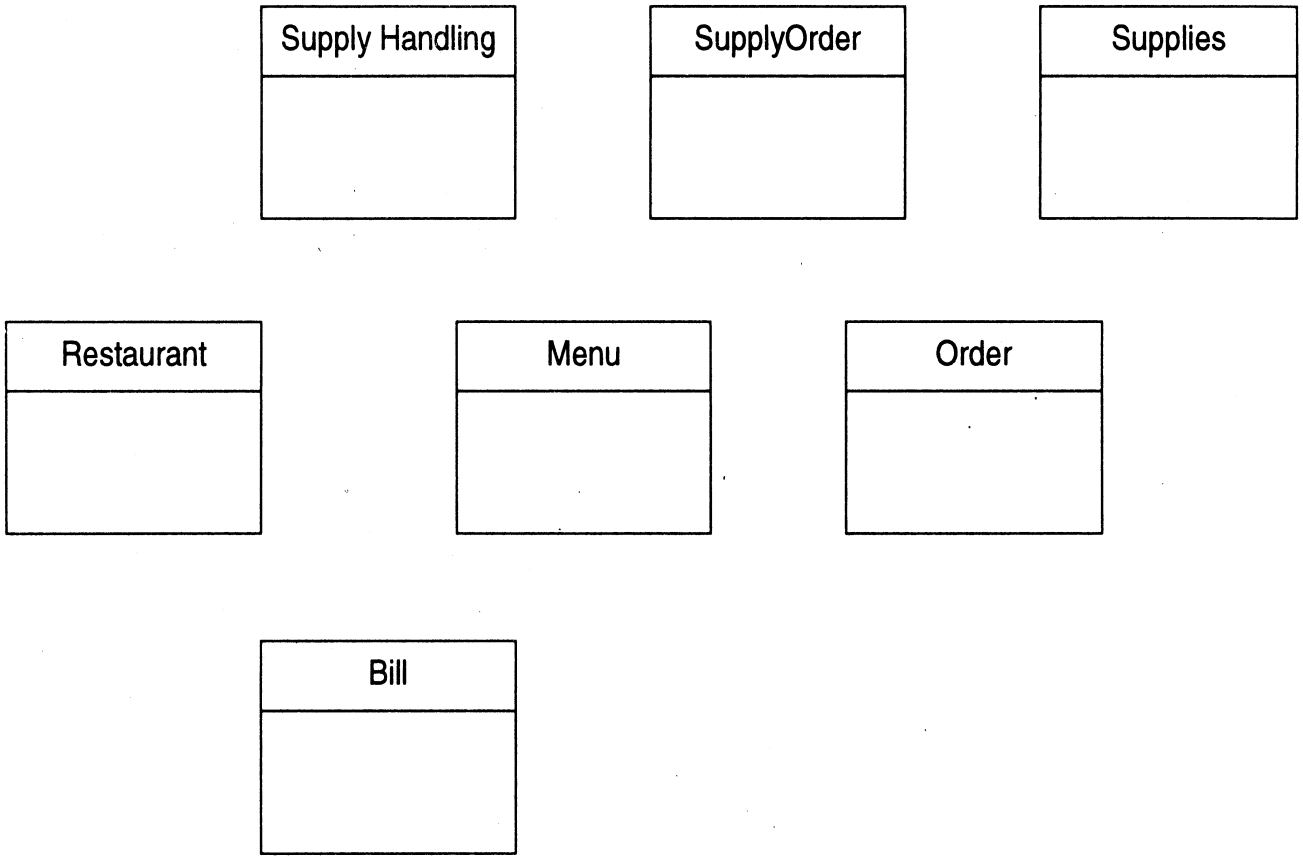
Design using UML

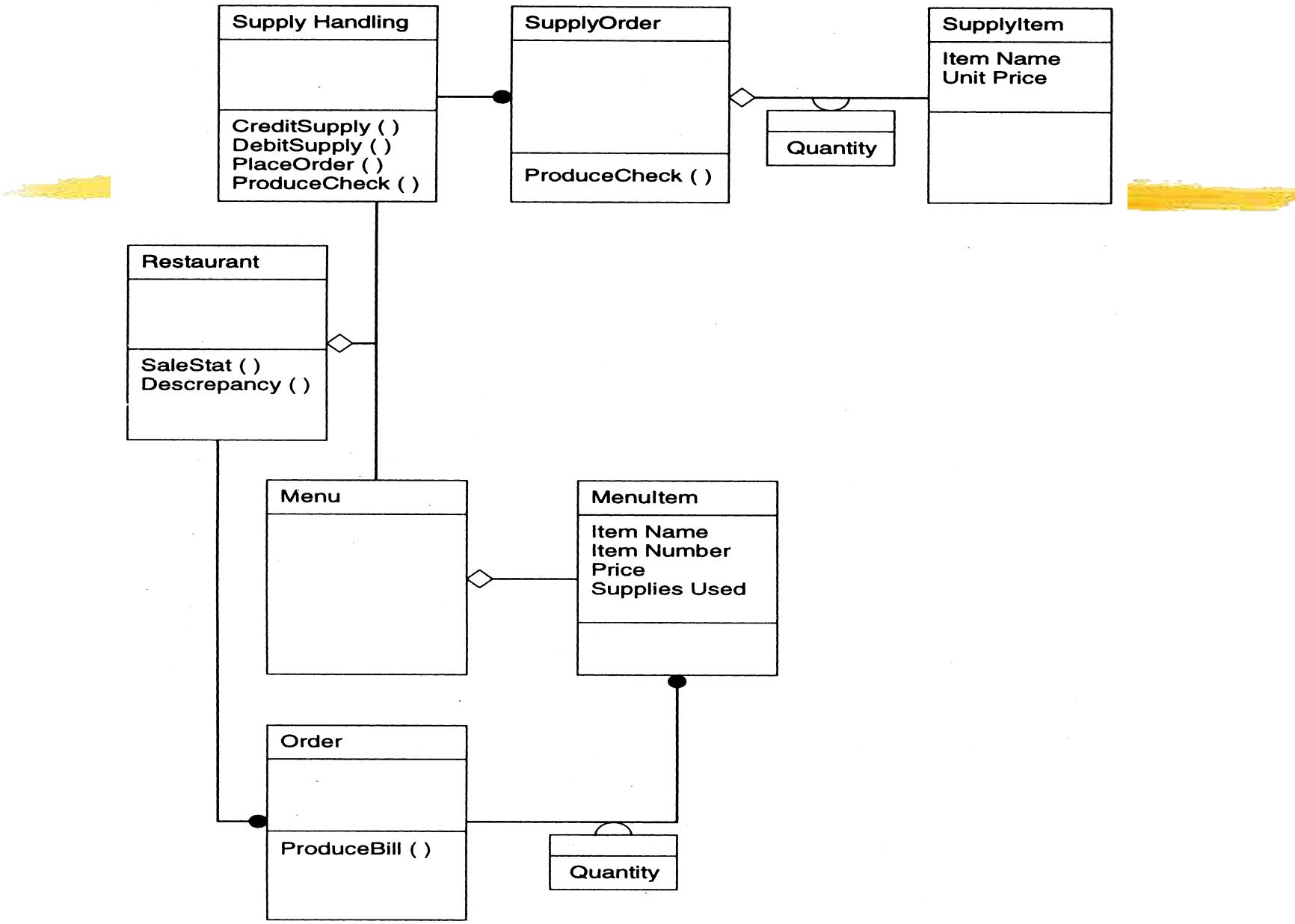
- Many OOAD methodologies have been proposed
- They provide some guidelines on the steps to be performed
- Basic goal is to identify classes, understand their behavior, and relationships
- Different UML models are used for this
- Often UML is used, methodologies are not followed strictly

Design using UML

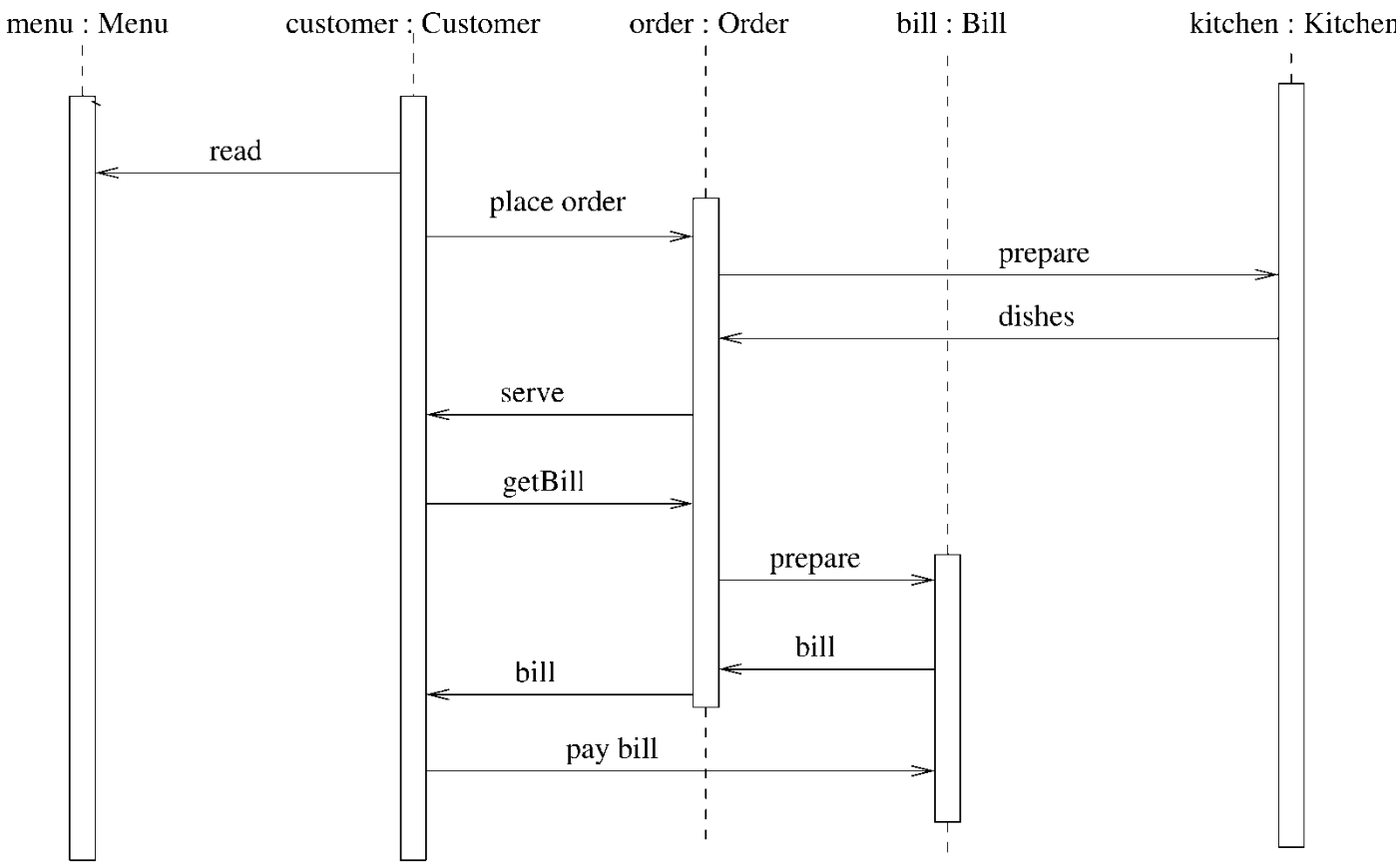
- Basic steps
  - Identify classes, attributes, and operations from use cases
  - Define relationships between classes
  - Make dynamic models for key use cases and use them to refine class diagrams
  - Make a functional model and use it to refine the classes
  - Optimize and package
- Class diagrams play the central role; class defn gets refined as we proceed

Restaurant example: Initial classes




Supply Handling
CreditSupply ( )
DebitSupply ( )
PlaceOrder ( )
ProduceCheck ( )
SupplyOrder
ProduceCheck ( )
Quantity
SupplyItem
Item Name
Unit Price
Restaurant
SaleStat ( )
Descrepancy ( )
Menu
MenuItem
Item Name
Item Number
Price
Supplies Used
Order
ProduceBill ( )
Quantity

Restaurant example: a seq diag



Detailed Design

- HLD does not specify module logic; this is done during detailed design
- One way to communicate the logic design: use natural language
- Is imprecise and can lead to misunderstanding
- Other extreme is to use a formal language
- Generally a semi-formal language is used – has formal outer structures but informal inside

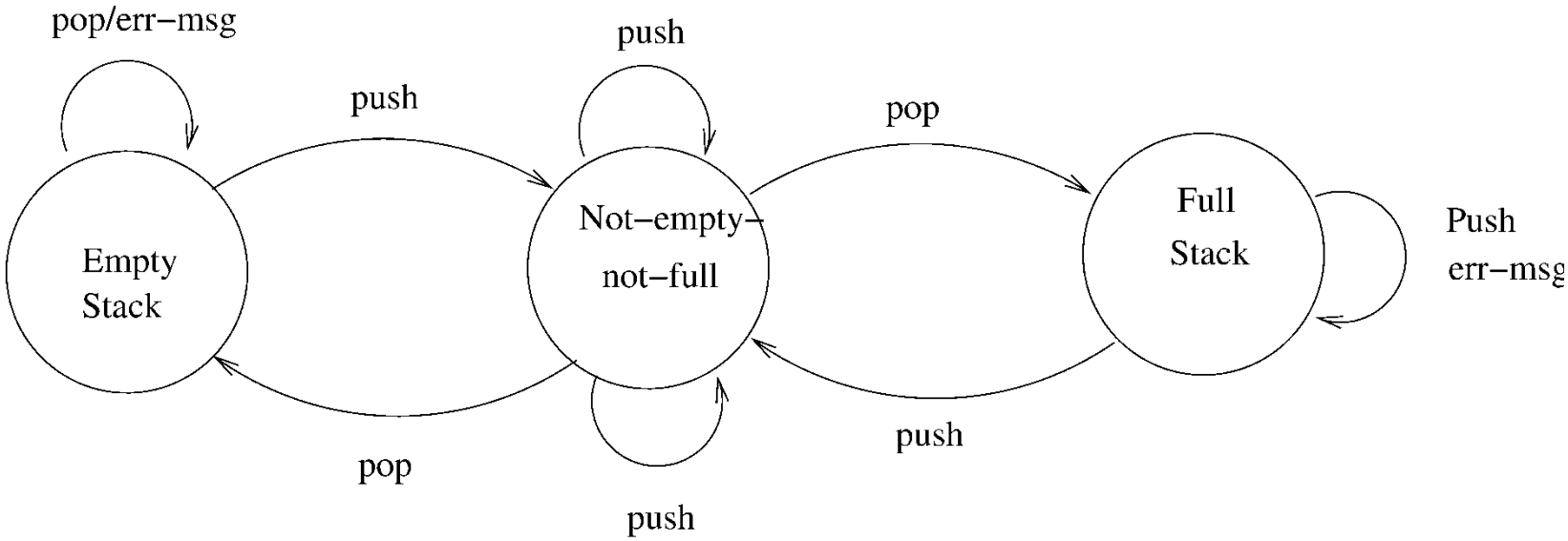
Logic/Algorithm Design

- Once the functional module (function or methods in a class) are specified, the algo to implement it is designed
- Various techniques possible for designing algorithm – in algos course
- Stepwise refinements technique is useful here

State Modeling of Classes

- Dynamic model to represent behavior of an individual object or a system
- Shows the states of an object and transitions between them
- Helps understand the object – focus only on the important logical states
- State diagrams can be very useful for automated and systematic testing

State diagram of a stack



Design Verification

- Main objective: does the design implement the requirements
- Analysis for performance, efficiency, etc may also be done
- If formal languages used for design representation, tools can help
- Design reviews remain the most common approach for verification

Metrics

Background

- Basic purpose to provide a quantitative evaluation of the design (so the final product can be better)
- Size is always a metric – after design it can be more accurately estimated
  - Number of modules and estimated size of each is one approach
- Complexity is another metric of interest – will discuss a few metrics

Network Metrics

- Focus on structure chart; a good SC is considered as one with each module having one caller (reduces coupling)
- The more the SC deviates from a tree, the more impure it is

  $$Graph\ impurity = n - e - 1$$

  n – *nodes,* e- *edges* in the graph
- Impurity of 0 means tree; as this no increases, the impurity increases

Stability Metrics

- Stability tries to capture the impact of a change on the design
- Higher the stability, the better it is
- Stability of a module – the number of assumptions made by other modules about this module
  - Depends on module interface, global data the module uses
  - Are known after design

Information Flow Metrics

- Complexity of a module is viewed as depending on intra-module complexity
- Intramodule estimated by module size and the information flowing
  - Size in LOC
  - Inflow – info flowing in the module
  - Outflow – info flowing out of the module
- $Dc = size * (inflow * outflow)^2$

Information flow metrics…

- (inflow * outflow) represents total combination of inputs and outputs
- Its square reps interconnection between the modules
- Size represents the internal complexity of the module
- Product represents the total complexity

Identifying error-prone modules

- Uses avg complexity of modules and std dev to identify error prone and complex modules:
  - Error prone: If Dc > avg complexity + std_dev
  - Complex: If avg complexity < Dc < avg + std dev
  - Normal: Otherwise

Complexity metrics for OO

- Weighted methods per class
  - Complexity of a class depends on no of classes and their complexity
  - Suppose complexity of methods is c1, c2..; by some functional complexity metric

    $WMC = \Sigma ci$
  - Large WMC might mean that the class is more fault-prone

OO Metrics...

- Depth of Inheritance Tree
  - DIT of C is depth from the root class
  - Length of the path from root to C
  - DIT is significant in predicting fault proneness
- Number of Children
  - Immediate no of subclasses of C
  - Gives a sense of reuse

OO Metrics...

- Coupling between classes
  - No of classes to which this class is coupled
  - Two classes are coupled if methods of one use methods or attr of other
  - Can be determined from code
  - (There are indirect forms of coupling that cannot be statically determined)

Metrics…

- Response for a class
  - The total no of methods that can be invoked from this class
  - Captures the strength of connections
- Lack of cohesion in methods
  - Two methods form a cohesive pair if they access some common vars (form a non-cohesive pair if no common var)
  - LCOM is the number of method pairs that are non-cohesive – the no of cohesive pairs

Metrics with detailed design

- When logic is known, internal complexity metrics can be determined
- We will cover all detailed design based metrics along with code metrics

Summary

- Design for a system is a plan for a solution – want correct and modular
- Cohesion and coupling key concepts to ensure modularity
- Structure charts and structured design methodology can be used for function-oriented design
- UML can be used for OO design
- Various complexity metrics exist to evaluate a design complexity