Lecture 6: Requirements Modeling II

Last Week:
Modeling Enterprises
General Modeling Issues
Modeling Human Activity,
i* etc.

This Week:
Modelling Information and Behaviour
Information Structure
Information Flow
Behaviour

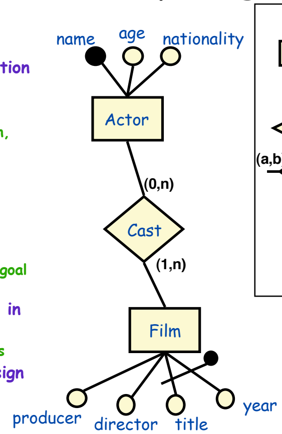
Next Week:
Non-functional requirements
Modelling NFRs
Analysis techniques for NFRs

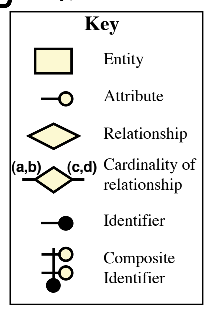
What to Model

- **Structure**
  - Entities (more usefully, classes of entities)
  - Relationships (whole/part, is-a, talks to…)
- **Behaviour**
  - States
  - Events
- **Interaction**
  - Communication patterns
  - Dataflow
  - Parallelism and coordination
  - Temporal dependencies

Entity Relationship Diagrams

- **ER diagrams**
  - widely used for information modeling
  - simple, easy to use
    - Note: this is a notation, not a method!
- **Used in many contexts:**
  - domain concepts
    - objects referred to in goal models, scenarios, etc.
  - Data to be represented in the system
    - for information systems
  - Relational Database design
  - Meta-modeling

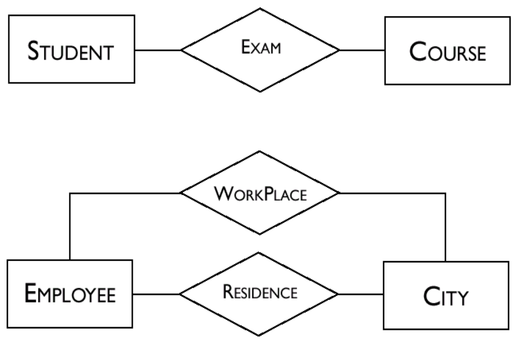




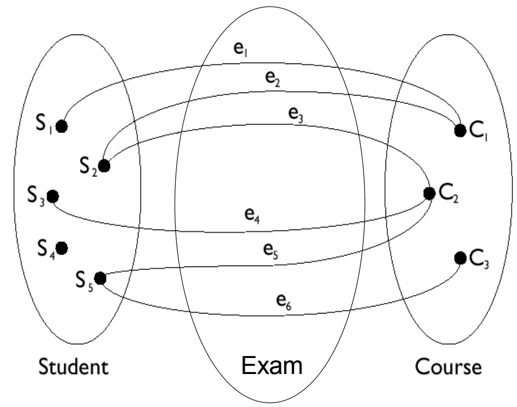
The Entity Relationship Model

- **Entity-Relationship Schema**
  - Describes data requirements for a new information system
  - Direct, easy-to-understand graphical notation
  - Translates readily to relational schema for database design
    - But more abstract than relational schema
    - E.g. can represent an entity without knowing its properties
  - comparable to UML class diagrams
- **Entities:**
  - classes of objects with properties in common and an autonomous existence
    - E.g. City, Department, Employee, Purchase and Sale
  - An instance of an entity is an object in the class represented by the entity
    - E.g. Stockholm, Helsinki, are examples of instances of the entity City
- **Relationships:**
  - logical links between two or more entities.
    - E.g. Residence is a relationship that can exist between the City and Employee
  - An instance of a relationship is an n-tuple of instances of entities
    - E.g. the pair (Johanssen,Stockholm), is an instance in the relationship Residence.

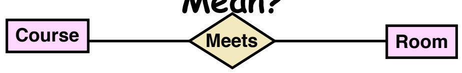
Examples



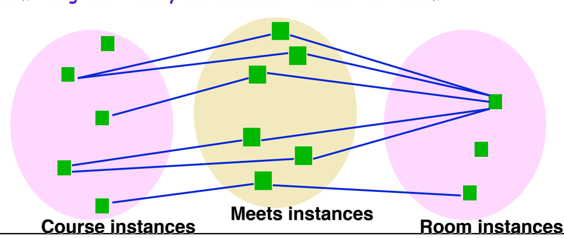
Example Instances for Exam



What Does An E-R Diagram Really Mean?

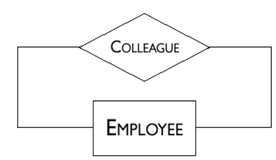


- **Course** and **Room** are entities.
  - Their instances are particular courses (eg CSC340F) and rooms (eg MB128)
- **Meets** is a relationship.
  - Its instances describe particular meetings.
  - Each meeting has exactly one associated course and room

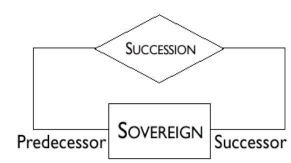


Recursive Relationships

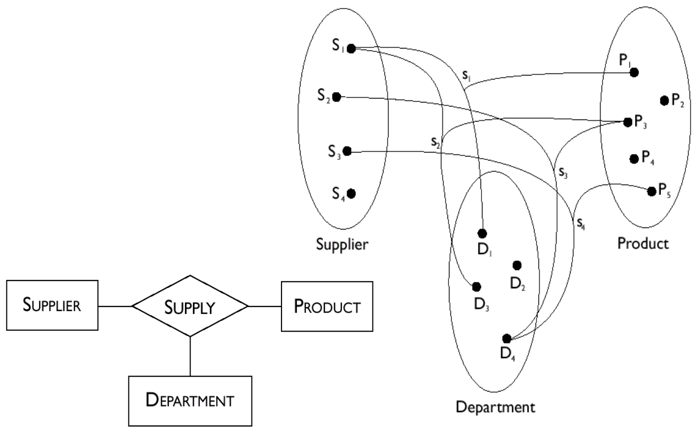
- an entity can have relationships with itself…



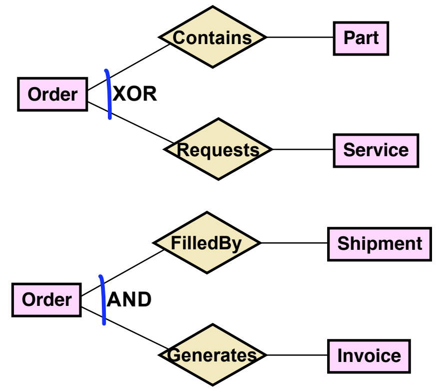
- If the relationship is not symmetric…
  - …need to indicate the two roles that the entity plays in the relationship.



Ternary Relationships



AND/XOR Relationships

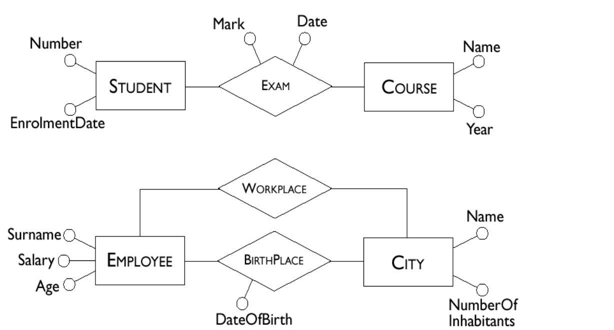


"Each Order either contains a part or requests a service, but not both"

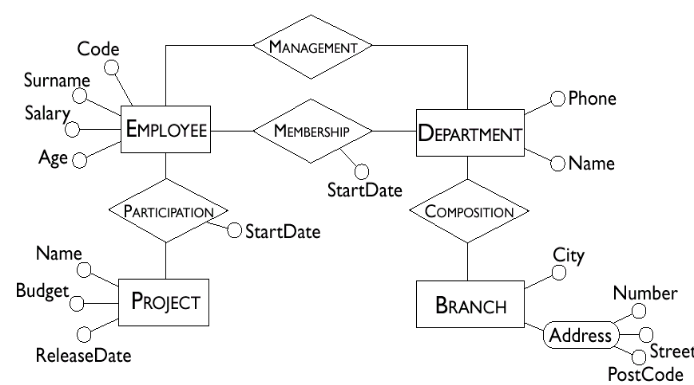
"For any given order, whenever there is at least one invoice there is also at least one shipment and vice versa"

Attributes

- **associates with each instance of an entity (or relationship) a value belonging to a set (the domain of the attribute).**
  - The domain determines the admissible values for the attribute.



Schema with Attributes



Cardinalities

→ **Cardinalities constrain participation in relationships**
- maximum and minimum number of relationship instances in which an entity instance can participate.
- E.g.

→ **cardinality is any pair of non-negative integers (a,b)**
- such that $a \leq b$.
- If a=0 then entity participation in a relationship is optional
- If a=1 then entity participation in a relationship is mandatory.
- If b=1 each instance of the entity is associated at most with a single instance of the relationship
- If b="N" then each instance of the entity is associated with an arbitrary number of instances of the relationship.

Object Oriented Analysis

→ **Background**
- Model the requirements in terms of objects and the services they provide
- Grew out of object oriented design
  - But applied to modelling the application domain rather than the program

→ **Motivation**
- OO is (claimed to be) more 'natural'
  - As a system evolves, the functions (processes) it performs tend to change, but the objects tend to remain unchanged
  - Hence a model based on functions/processes will get out of date, but an object oriented model will not…
  - …hence the claim that object-oriented designs are more maintainable
- OO emphasizes importance of well-defined interfaces between objects
  - compared to ambiguities of dataflow relationships

NOTE: OO applies to requirements engineering because it is a modeling tool. But we are modeling domain objects, not the design of the new system

Nearly anything can be an object…

Source: Adapted from Pressman, 1994, p242

→ **External Entities**
- …that interact with the system being modeled
  - E.g. people, devices, other systems

→ **Things**
- …that are part of the domain being modeled
  - E.g. reports, displays, signals, etc.

→ **Occurrences or Events**
- …that occur in the context of the system
  - E.g. transfer of resources, a control action, etc.

→ **Roles**
- played by people who interact with the system

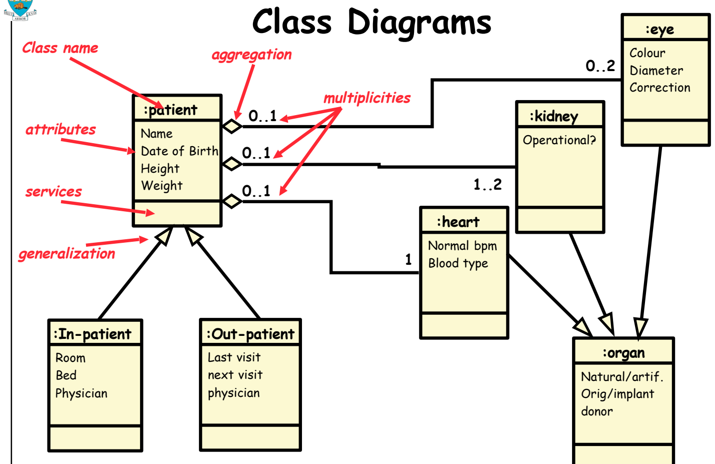
→ **Organizational Units**
- that are relevant to the application
  - E.g. division, group, team, etc.

→ **Places**
- …that establish the context of the problem being modeled
  - E.g. manufacturing floor, loading dock, etc.

→ **Structures**
- that define a class or assembly of objects
  - E.g. sensors, four-wheeled vehicles, computers, etc.

Some things cannot be objects:
- *procedures (e.g. print, invert, etc)*
- *attributes (e.g. blue, 50Mb, etc)*

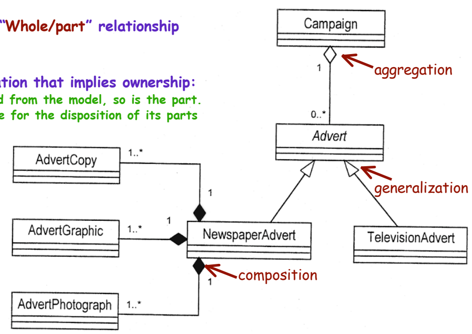
Class Diagrams



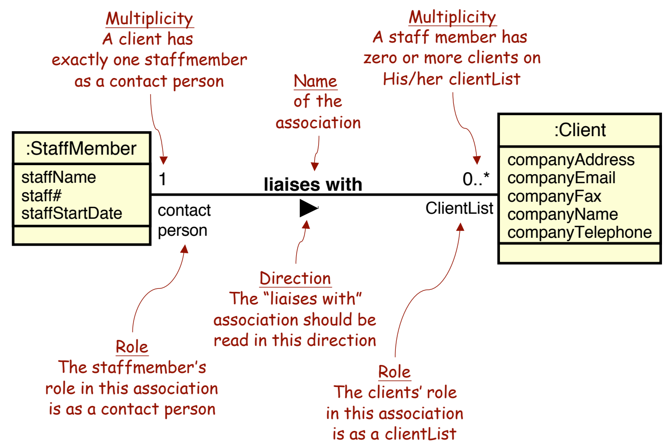
Generalization vs Aggregation

Source: Examples from Bennett, McRobb & Farmer, 2002

- Generalization
  - Subclasses inherit attributes, associations, & operations from the superclass
  - A subclass may override an inherited aspect
- Aggregation
  - This is the "Has-a" or "Whole/part" relationship
- Composition
  - Strong form of aggregation that implies ownership:
    - if the whole is removed from the model, so is the part.
    - the whole is responsible for the disposition of its parts

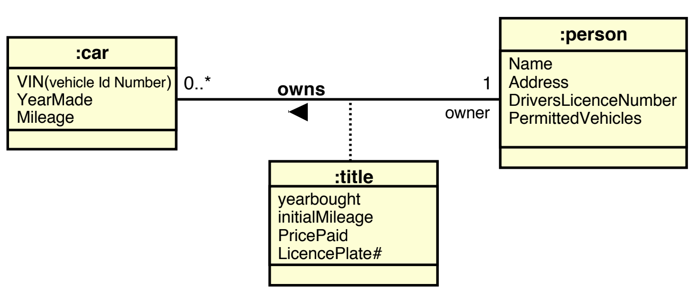


Class associations



Association Classes

- Sometimes the association is itself a class
  - ...because we need to retain information about the association
  - ...and that information doesn't naturally live in the classes at the ends of the association
    - E.g. a "title" is an object that represents information about the relationship between an owner and her car



Aggregation and Composition

- Aggregation
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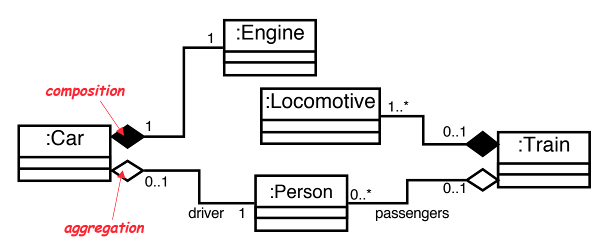
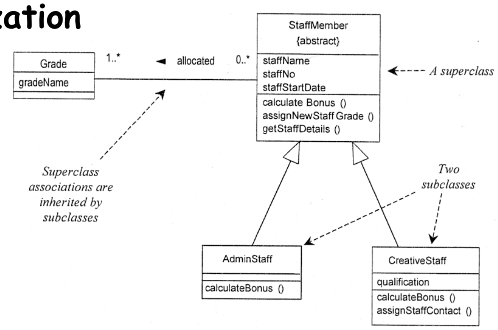


Generalization



- **Notes:**
  - Subclasses inherit attributes, associations, & operations from the superclass
  - A subclass may override an inherited aspect
    - e.g. AdminStaff & CreativeStaff have different methods for calculating bonuses
  - Superclasses may be declared **{abstract}**, meaning they have no instances
    - Implies that the subclasses cover all possibilities
    - e.g. there are no other staff than AdminStaff and CreativeStaff

More on Generalization

- **Usefulness of generalization**
  - Can easily add new subclasses if the organization changes
- **Look for generalizations in two ways:**
  - Top Down
    - You have a class, and discover it can be subdivided
    - Or you have an association that expresses a "kind of" relationship
    - *E.g. "Most of our work is on advertising for the press, that's newspapers and magazines, also for advertising hoardings, as well as for videos"*
  - Bottom Up
    - You notice similarities between classes you have identified
    - E.g. *"We have books and we have CDs in the collection, but they are all filed using the Dewey system, and they can all be lent out and reserved"*
- **But don't generalize just for the sake of it**
  - Be sure that everything about the superclass applies to the subclasses
  - Be sure that the superclass is useful as a class in its own right
    - I.e. not one that we would discard using our tests for useful classes
  - Don't add subclasses or superclasses that are not relevant to your analysis

Variants

- **Coad-Yourdon**
  - Developed in the late 80's
  - Five-step analysis method
- **Shlaer-Mellor**
  - Developed in the late 80's
  - Emphasizes modeling information and state, rather than object interfaces
- **Fusion**
  - Second generation OO method
  - Introduced use-cases
- **Unified Modeling Language (UML)**
  - Third generation OO method
  - An attempt to combine advantages of previous methods

Example method: Coad-Yourdon

***Source:** Adapted from Pressman, 1994, p242 and Davis 1990, p98-99*

- **Five Step Process:**
  1. Identify Objects & Classes *(i.e. 'is_a' relationships)*
  2. Identify Structures *(i.e. 'part_of' relationships)*
  3. Define Subjects
     - A more abstract view of a large collection of objects
     - Each classification and assembly structure become one subject
     - Each remaining singleton object becomes a subject *(although if there a many of these, look for more structure!)*
     - Subject Diagram shows only the subjects and their interactions
  4. Define Attributes and instance connections

  5a. Define services - 3 types:
     - Occur (create, connect, access, release) *These are omitted from the model as every object has them*
     - Calculate (when a calculated result from one object is needed by another)
     - Monitor (when an object monitors for a condition or event)

  5b. Define message connections
     - These show how services of one object are used by another
     - Shown as dotted lines on object and subject diagrams
     - Each message may contain parameters

Unified Modeling Language

→ Third generation OO method

- Booch, Rumbaugh & Jacobson are principal authors
  - Still in development
  - Attempt to standardize the proliferation of OO variants
- Is purely a notation
  - No modeling method associated with it!
- But has been accepted as a standard for OO modeling
  - But is primarily owned by Rational Corp. (who sell lots of UML tools and services)

→ Has a standardized meta-model

- Use case diagrams
- Class diagrams
- Message sequence charts
- Activity diagrams
- State Diagrams (uses Harel's statecharts)
- Module Diagrams
- Platform diagrams

Evaluation of OOA

→ Advantages of OO analysis for RE

- Fits well with the use of OO for design and implementation
  - Transition from OOA to OOD 'smoother' (but is it?)
- Removes emphasis on functions as a way of structuring the analysis
- Avoids the fragmentary nature of structured analysis
  - object-orientation is a coherent way of understanding the world

→ Disadvantages

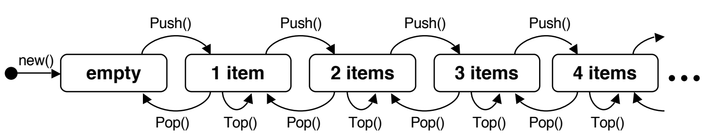
- Emphasis on objects brings an emphasis on static modeling
  - although later variants have introduced dynamic models
- Not clear that the modeling primitives are appropriate
  - are objects, services and relationships really the things we need to model in RE?
- Strong temptation to do design rather than problem analysis
- Fragmentation of the analysis
  - E.g. reliance on use-cases means there is no "big picture" of the user's needs
- Too much marketing hype!
  - and false claims - e.g. no evidence that objects are a more natural way to think

Modelling Behaviour

→ All objects have "state"

- The object either exists or it doesn't
- If it exists, then it has a value for each of its attributes
- Each possible assignment of values to attributes is a "state"
  - (and non-existence is a state, although we normally ignore it)

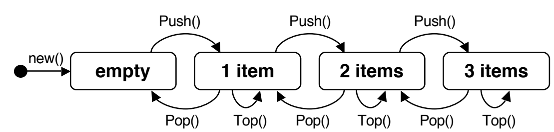
→ E.g. For a stack object



What does the model mean?

→ Finite State Machines

- There are a finite number of states (all attributes have finite ranges)
  - E.g. imagine a stack with max length = 3



- The model specifies a set of traces
  - E.g. new();Push();Push();Top();Pop();Push()…
  - E.g. new();Push();Pop();Push();Pop()…
  - There may be an infinite number of traces (and traces may be of infinite length)
- The model excludes some behaviours
  - E.g. no trace can start with a Pop()
  - E.g. no trace may have more Pops than Pushes
  - E.g. no trace may have more than 3 Pushes without a Pop in between

Abstraction

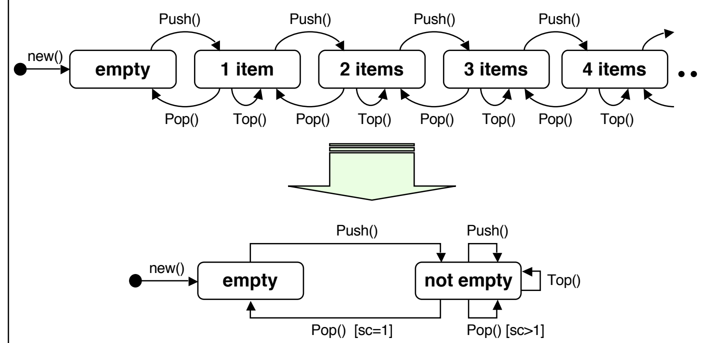
→ **The state space of most objects is enormous**

- State space size is the product of the range of each attribute
  - E.g. object with five boolean attributes: 2^5+1 states
  - E.g. object with five integer attributes: $(maxint)^5+1$ states
  - E.g. object with five real-valued attributes: …?
- If we ignore computer representation limits, the state space is infinite

→ **Only part of that state space is "interesting"**

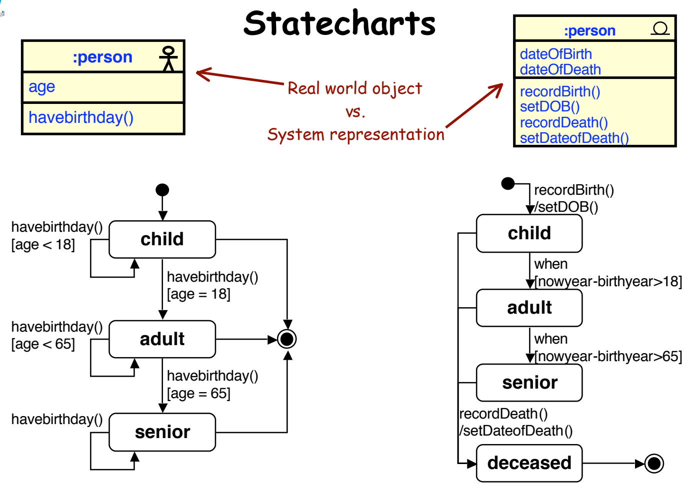
- Some states are not reachable
- Integer and real values usually only vary within some relevant range
- We're usually not interested in the actual values, just certain ranges:
  - E.g. for Age, we may be interested in age<18; 18≤age≤65; and age>65
  - E.g. for Cost, we may only be interested in cost≤budget, cost=0, cost>budget, and cost>(budget+10%)

Collapsing the state space



- The abstraction usually permits more traces
  - E.g. this model does not prevent traces with more pops than pushes
  - But it still says something useful

Statecharts



States and Transitions

→ **A state represents a time period during which**

- A predicate is true
  - e.g. (budget - expenses) > 0,
- An action is being performed, or an event is awaited:
  - e.g. checking inventory for order items
  - e.g. waiting for arrival of a missing order item

→ **A state can be "on" or "off".**

- When a state is "on", all its outgoing transitions are eligible to fire.
- Transitions take the form:

  event(parameters) [guard] / action

  - For a transition to fire, its event must occur and its guard must be true.
  - When a transition fires, its action is carried out.

→ **States can have associated activities:**

- do/activity
  - carries out some activity for as long as the state is "on"
- entry/action and exit/action
  - carry out the action whenever the state is entered (exited)
- include/stateDiagramName
  - "calls" another state diagram, allowing state diagrams to be nested

Events

→ **Events are happenings the system needs to know about**
- Must be relevant to the system (or object) being modelled
- Must be modellable as an instantaneous occurance (from the system's point of view)
  - E.g. completing an assignment, failing an exam, a system crash
- Are implemented by message passing in an OO Design

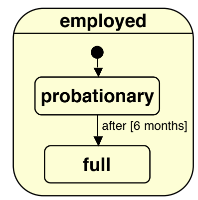
→ **In UML, there are four types of events:**
- *Change events* occur when a condition becomes true
  - denoted by the keyword 'when'
  - e.g. when[balance < 0]
- *Call events* occur when an object receives a call for one of its operations to be perfomed
- *Signal events* occur when an object receives an explicit (real-time) signal
- *Elapsed-time events* mark the passage of a designated period of time
  - e.g. after[10 seconds]

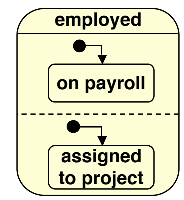
Superstates

→ **States can be nested, to make diagrams simpler**
- A superstate consists of one or more states.
- Superstates make it possible to view a state diagram at different levels of abstraction.

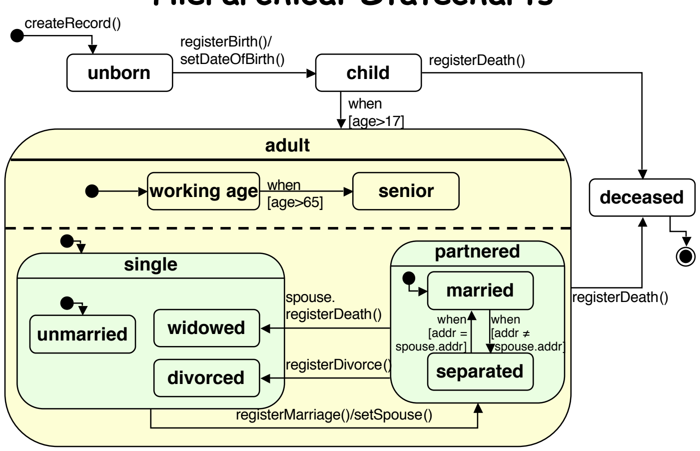
→ **OR superstates**
- when the superstate is "on", only one of its substates is "on"

→ **AND superstates (concurrent substates)**
- When the superstate is "on", all of its states are also "on"
- Usually, the AND substates will be nested further as OR superstates





Hierarchical Statecharts



Checking your Statecharts

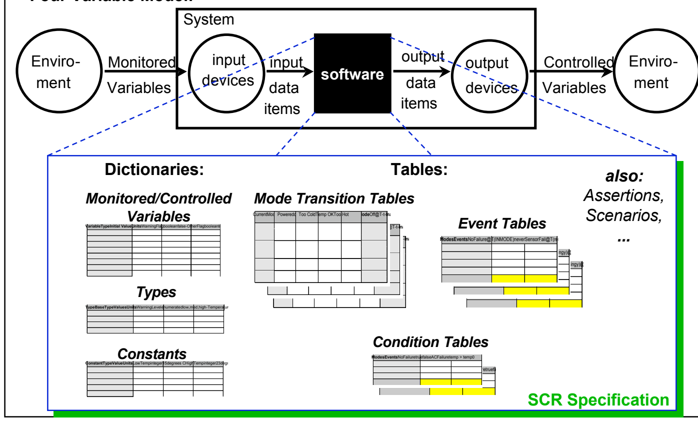
→ **Consistency Checks**
- All events in a statechart should appear as:
  - operations of an appropriate class in the class diagram **and**
  - incoming messages for this object on a collaboration/sequence diagram
- All actions in a statechart should appear as:
  - operations of an appropriate class in the class diagram and
  - outgoing messages for this object on a collaboration/sequence diagram

→ **Style Guidelines**
- Give each state a unique, meaningful name
- Only use superstates when the state behaviour is genuinely complex
- Do not show too much detail on a single statechart
- Use guard conditions carefully to ensure statechart is unambiguous
  - Statecharts should be deterministic (unless there is a good reason)

→ **You probably shouldn't be using statecharts if:**
- you find that most transitions are fired "when the state completes"
- many of the trigger events are sent from the object to itself
- your states do not correspond to the attribute assignments of the class

Tabular Specifications: SCR

Four Variable Model:



SCR basics

→ Modes and Mode classes

- A mode class is a finite state machine, with states called *system modes*
  - Transitions in each mode class are triggered by *events*
- Complex systems are described using a number of mode classes operating in parallel

→ System State

- A (system) state is defined as:
  - the system is in exactly one mode from each mode class…
  - …and each variable has a unique value

→ Events

- An event occurs when any system entity changes value
  - An *input event* occurs when an *input* variable changes value
  - Single input assumption - only one input event can occur at once
  - Notation: @T(c) means "c changed from false to true"
- A conditioned event is an event with a predicate
  - @T(c) WHEN d means: "c became true when c *was* false and d *was* true"

Defining Mode Classes

→ Mode Class Tables

- Define a (disjoint) set of *modes* (states) that the software can be in.
- A complex system will have many different modes classes
  - Each mode class has a mode table showing the events that cause transitions between modes
- A mode table defines a *partial function* from modes and events to modes

→ Example:

Current Mode	Powered on	Too Cold	Temp OK	Too Hot	**New Mode**
Off	@T	-	t	-	**Inactive**
	@T	t	-	-	**Heat**
	@T	-	-	t	**AC**
Inactive	@F	-	-	-	**Off**
	-	@T	-	-	**Heat**
	-	-	-	@T	**AC**
Heat	@F	-	-	-	**Off**
	-	-	@T	-	**Inactive**
AC	@F	-	-	-	**Off**
	-	-	@T	-	**Inactive**

Defining Controlled Variables

→ Event Tables

- defines how a controlled variable changes in response to input events
- Defines a *partial function* from modes and events to variable values
- Example:

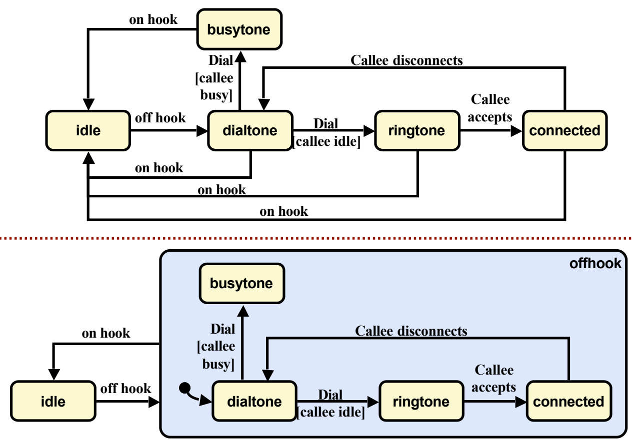
Modes		
Heat, AC	@C(target)	never
Inactive, Off	never	@C(target)
Ack_tone =	**Beep**	**Clang**

→ Condition Tables

- defines the value of a controlled variable under every possible condition
- Defines a *total function* from modes and conditions to variable values
- Example:

Modes		
Heat	target - temp ≤ 5	target - temp >5
AC	temp - target ≤ 5	temp - target >5
Inactive, Off	true	never
Warning light =	**Off**	**On**

Refresher: FSMs and Statecharts



SCR Equivalent

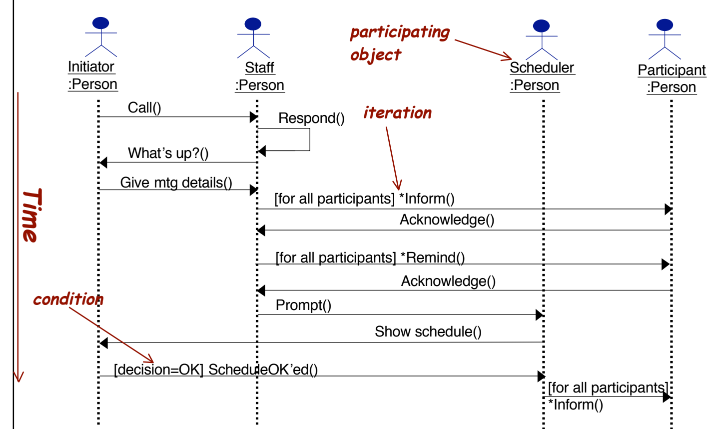
Current Mode	offhook	dial	callee offhook	New Mode
Idle	@T	-	-	Dialtone
Dialtone	-	@T	F	Ringtone
	-	@T	T	Busytone
	@F	-	-	Idle
Busytone	@F	-	-	Idle
Ringtone	-	-	@T	Connected
	@F	-	-	Idle
Connected	-	-	@F	Dialtone
AC	@F	-	-	Idle

- **Interpretation:**
  - In Dialtone: @T(offhook) WHEN callee_offhook takes you to Ringing
  - In Ringtone: @F(offhook) takes you to Idle
  - Etc...

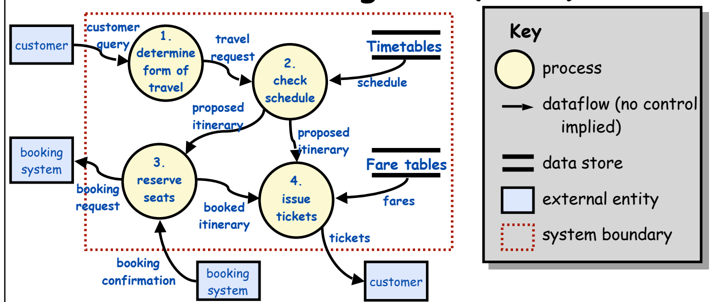
State Machine Models vs. SCR

- **All 3 models on previous slides are (approx) equivalent**
- **State machine models**
  - Emphasis is on states & transitions
    - No systematic treatment of events
    - Different event semantics can be applied
  - Graphical notation easy to understand (?)
  - Composition achieved through statechart nesting
  - Hard to represent complex conditions on transitions
  - Hard to represent real-time constraints (e.g. elapsed time)
- **SCR models**
  - Emphasis is on events
    - Clear event semantics based on changes to environmental variables
    - Single input assumption simplifies modelling
  - Tabular notation easy to understand (?)
  - Composition achieved through parallel mode classes
  - Hard to represent real-time constraints (e.g. elapsed time)

UML Sequence Diagrams

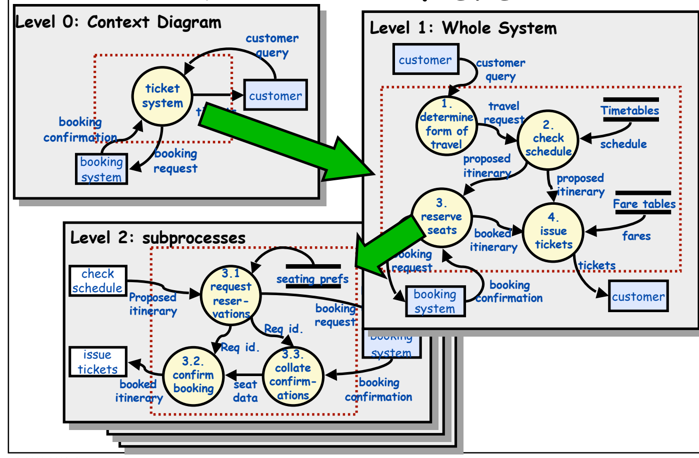


Dataflow Diagrams (DFDs)



→ Notes:
- every process, flow, and datastore must be labeled
- representation is hierarchical
  - each process will be represented separately as a lower level DFD
- processes are normally numbered for cross reference
- processes transform data
  - can't have the same data flowing out of a process as flows into it

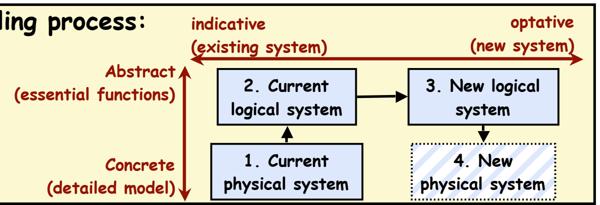
Hierarchies of DFDs



Structured Analysis

→ Definition
- Structured Analysis is a data-oriented approach to conceptual modeling
- Common feature is the centrality of the dataflow diagram
- Mainly used for information systems
  - variants have been adapted for real-time systems

→ Modeling process:



- Model of current physical system only useful as basis for the logical model
- Distinction between indicative and optative models is very important:
  - Must understand which requirements are needed to continue current functionality, and which are new with the updated system

Variants

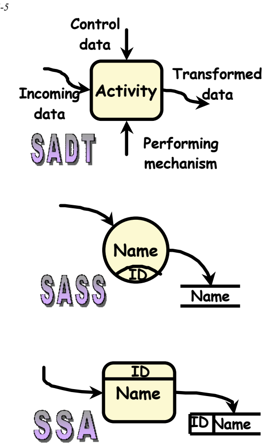
Source: *Adapted from Svoboda, 1990, p264-5*

→ Structured Analysis and Design Technique (SADT)
- Developed by Doug Ross in the mid-70's
- Uses activity diagrams rather than dataflow diagrams
- Distinguishes control data from processing data

→ Structured Analysis and System Specification (SASS)
- Developed by Yourdon and DeMarco in the mid-70's
- 'classic' structured analysis

→ Structured System Analysis (SSA)
- Developed by Gane and Sarson
- Notation similar to Yourdon & DeMarco
- Adds data access diagrams to describe contents of data stores

→ Structured Requirements Definition (SRD)
- Developed by Ken Orr in the mid-70's
- Introduces the idea of building separate models for each perspective and then merging them



Example method: SASS

Source: Adapted from Davis, 1990, p83-86

1. **Study current environment**
   - draw DFD to show how data flows through current organization
   - label bubbles with names of organizational units or individuals
2. **Derive logical equivalents**
   - replace names (of people, roles,…) with action verbs
   - merge bubbles that show the same logical function
   - delete bubbles that don't transform data
3. **Model new logical system**
   - Modify logical DFD to show how info will flow once new system is in place
     - …but don't distinguish (yet) which components will be automated
4. **Define a number of automation alternatives**
   - document each as a physical DFD
   - Analyze each with cost/benefit trade-off
   - Select one for implementation
   - Write the specification

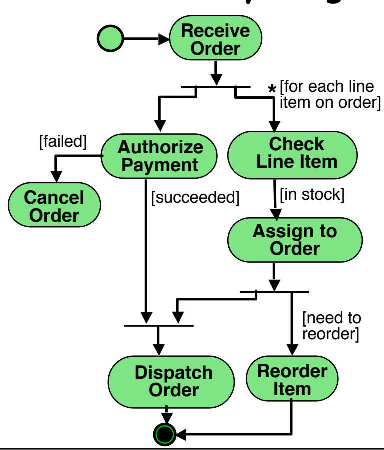
Evaluation of SA techniques

Source: Adapted from Davis, 1990, p174

→ **Advantages**
- Facilitates communication.
- Notations are easy to learn, and don't require software expertise
- Clear definition of system boundary
- Use of abstraction and partitioning
- Automated tool support
  - e.g. CASE tools provide automated consistency checking

→ **Disadvantages**
- Little use of projection
  - even SRD's 'perspectives' are not really projection
- Confusion between modeling the problem and modeling the solution
  - most of these techniques arose as design techniques
- These approaches model the system, *but not its application domain*
- Timing issues are completely invisible

UML Activity Diagrams



Activity Diagram with Swimlanes