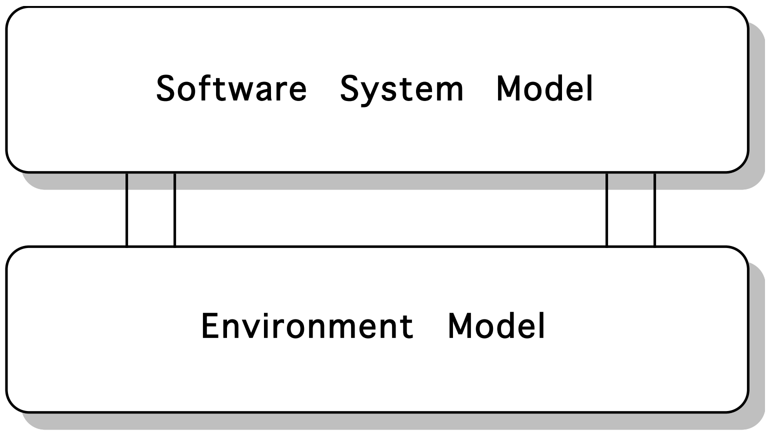
6. Basic Methods

Overview

- 6.1 Models
- 6.2 Taxonomy
- 6.3 Finite State Model
- 6.4 State Transition Model
- 6.5 Dataflow Model
- 6.6 User Manual

6.1 Models

- Existing techniques focus on functional specifications
  - the relation between the system and its environment
- Specifications vary greatly in style and notation
  - semi-formal (specialized notation)
  - formal (mathematics and logics)
- Each method is based on an underlying model of computing

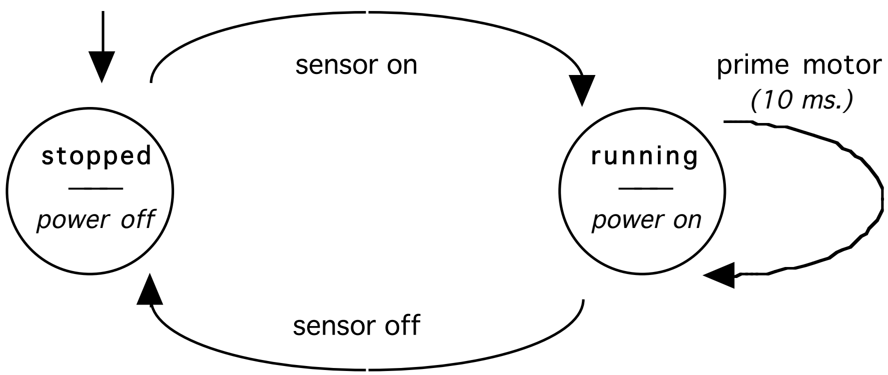


Choosing the Right Model

- The choice of model is determined by the need for precise and concise communication
- Aspects of the specification that do not fit the model are left out or are treated using other models
- When multiple models are used, consistency becomes a critical verification concern
- The document organization is determined by the nature of the model

A Finite State Machine Model

- External actions associated with entry in a state



Documentation implications

3. Specific Requirements

3.1 Initial state

Startup action

3.2 State S

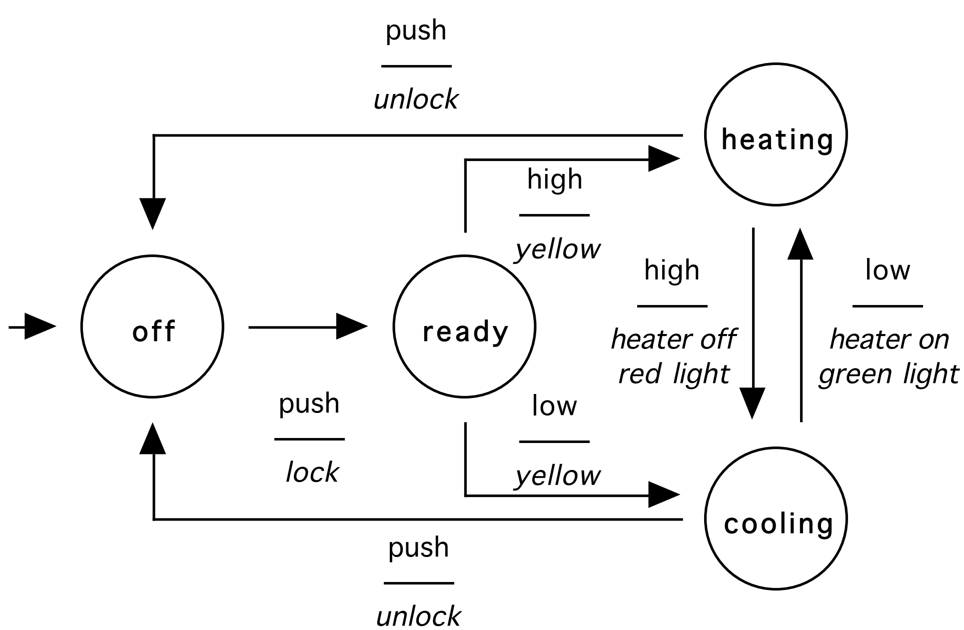
3.2.1Action A

3.2.2Event X

Next State S’

Another Machine Model

- External actions associated with transitions



Documentation implications

3. Specific Requirements

3.1 Initial state

Initialization

3.2 State A

3.2.1 Event X

Next State S'

Action A

6.2 Taxonomy

Type of underlying model

- Operational
  - finite state
  - state transition systems
  - concurrent processes
  - dataflow
  - applicative
- Descriptive
  - data models
  - algebraic
  - logic
  - object-oriented

6.3 Finite State Model

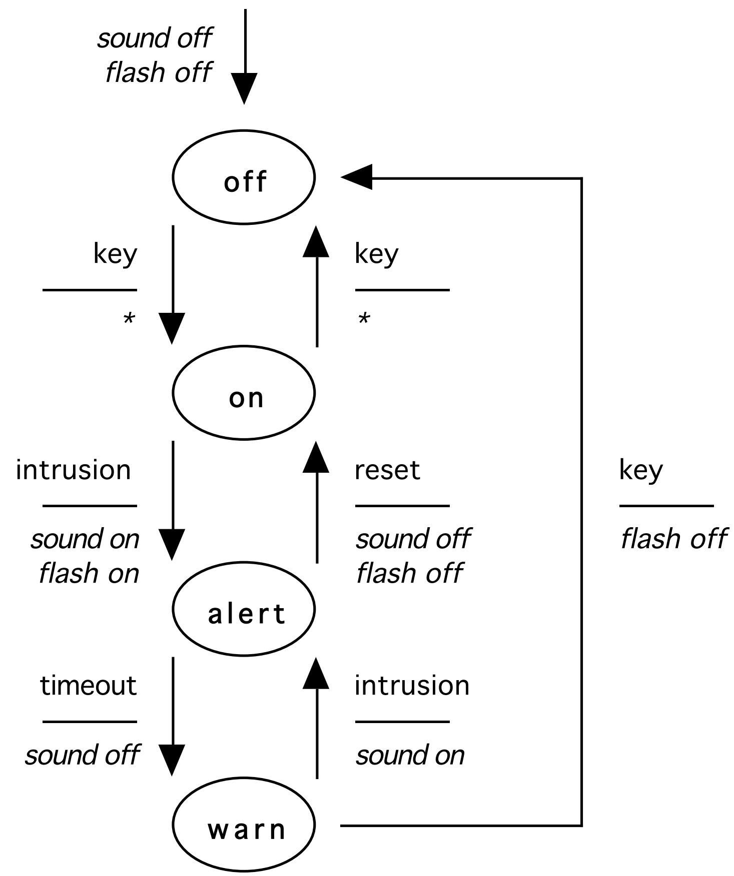
Reactive Control Applications

- Environment (abstract external interfaces)
  - sensor behavior can be reduced to a finite set of input events
  - actuator controls can be reduced to a finite set of output events
- System (software functionality)
  - control logic requires a finite set of states
  - behavior is deterministic

Model

Home safety alarm

- What is a “timeout” event?
- Is the specification correct?



Documentation

1. Introduction
2. General description
3. Specific requirements

   …

4. Performance requirements
5. Design constraints
6. Attributes
7. Other requirements

3.1 External interfaces

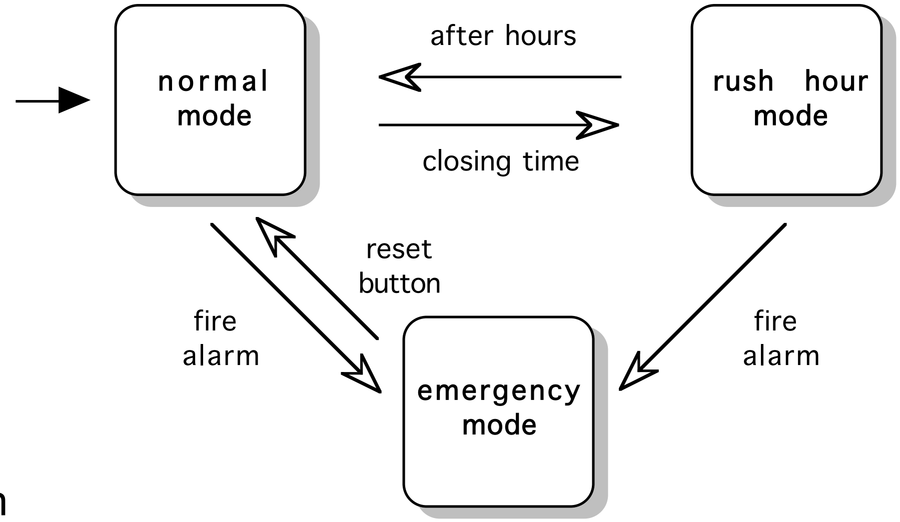
- *input events and output actions*
- *relation to physical devices*

3.2 Control logic

- *diagram, table, or text*

Complexity Control

- State explosion can be avoided often by separating the system behavior into distinct modes
- A finite state diagram can capture the mode transition rules
- Uniform rules must govern the transitions from mode to mode
  - a mode is always entered in the initial state or in specially denoted states
  - a mode can be exited from every state or only from marked states

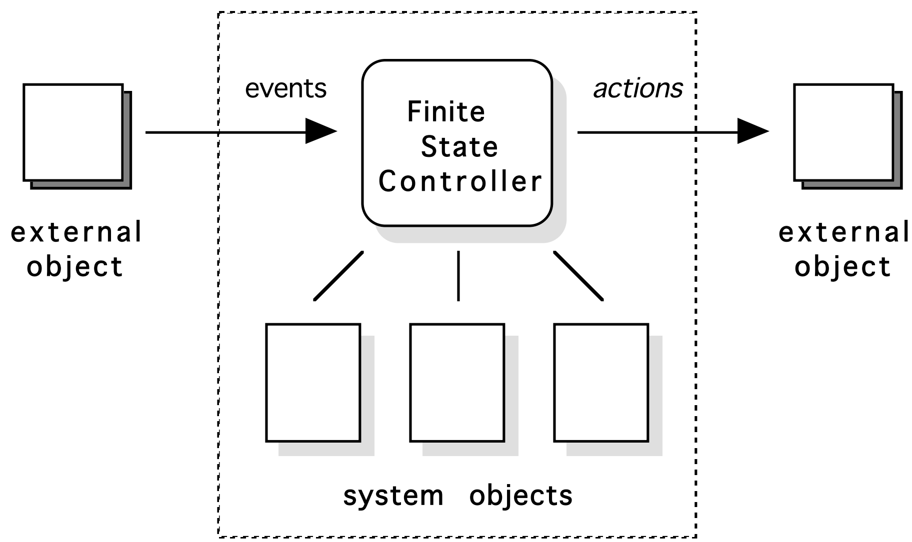


Object-Oriented Variations

- Interfaces are encapsulated as external objects
  - a step towards an object-oriented design
- Non-finite-state aspects of the system are encapsulated in internal objects
  - these objects have little or no implication on the subsequent design structure

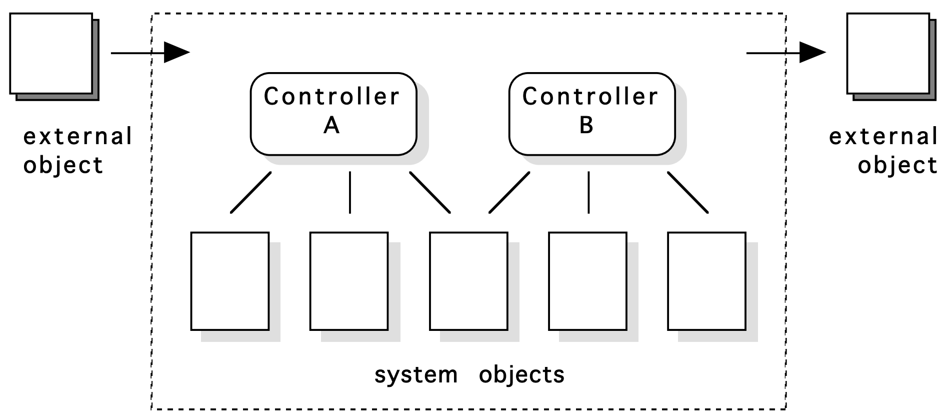
Object-Oriented Variations

- Events may be external or internal (conditions)
- Actions may be external or internal (operations)



Controlling State Explosion

- Model complexity can be reduced significantly by employing multiple parallel controllers
- Decoupling and limited object sharing simplify analysis
- Direct implementation of the model is sometimes feasible

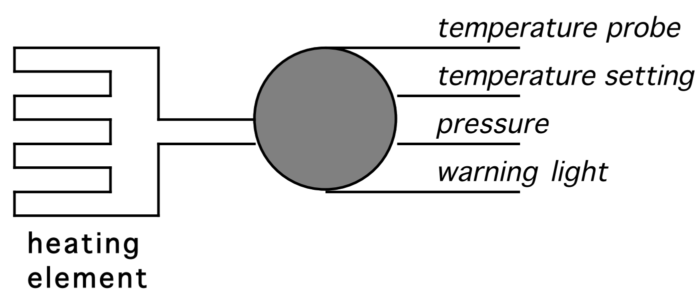


Case Study: Hot Water Heater

- During the preheating period (first 2 minutes) the heating element is on continuously.
- Continuous hot water output requires the heating element to stay on for 50% of the time while water is needed (low pressure).
- If the heater is no longer able to provide a continuous hot water supply (temperature drop), a warning light must turn on and the heating element must remain on for as long as water is needed.

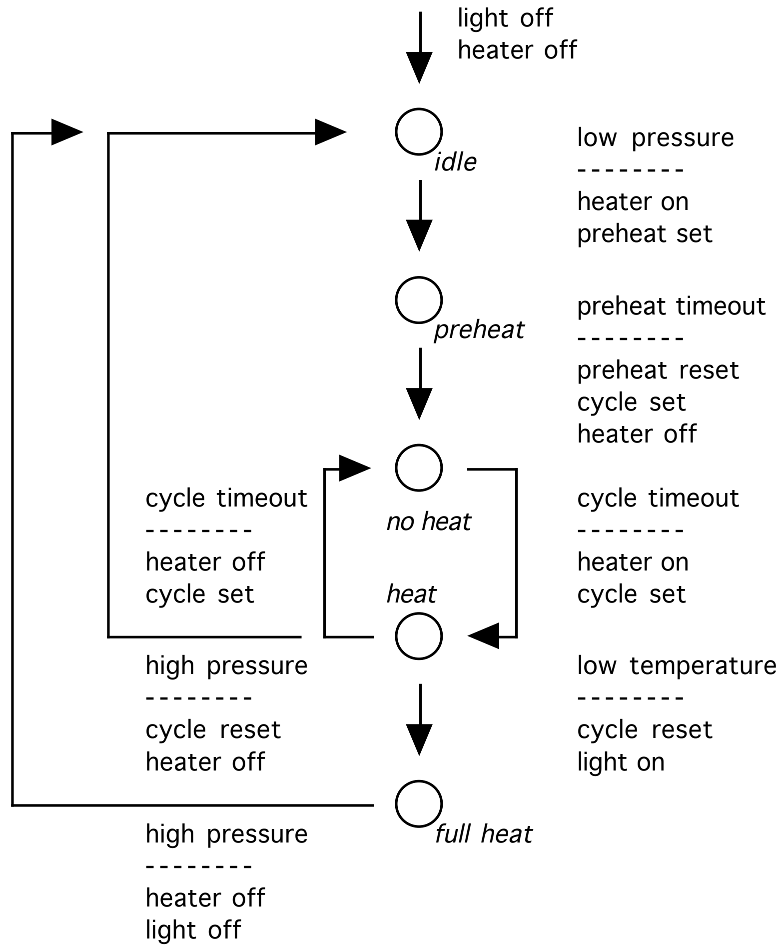
Case Study: Hot Water Heater

- Environment (objects)
  - heating element
    - on/off
  - temperature probe & temperature setting
    - low temperature
  - pressure sensor
    - low/high
  - warning light
    - on/off
- Virtual environment objects
  - preheat timer (2 minutes)
    - set, reset, timeout
  - cycle timer (1 second)



Case Study: Hot Water Heater

- Analysis:
  - Can the temperature drop without heating coming on?
  - *[idle]*



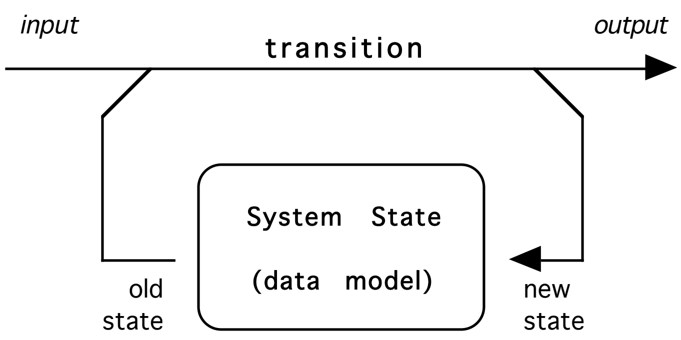
6.4 State Transition Model

Data Processing Applications

- Environment (abstract external interfaces)
  - inputs are data records supplied in a nondeterministic manner
  - outputs are immediately consumed data records
- System (software functionality)
  - the system maintains significant amounts of data
  - system operation involves data updating and output computation in response to input arrival

Model

- Data models are used to characterize the system state
- Operations
  - are associated with the arrival of input
  - are atomic
  - result in a state change and output generation
- Virtual inputs may be added to model periodic activities, time-dependent processing, etc.



Documentation

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3.1 External interfaces

- *inputs and outputs*
- *relation to physical devices*

3.2 Data model

- *text, tables, etc.*

3.3 Operations

- *grouped by some organizing principle*

Operational Specifications

- Operations can be specified as abstract procedures
- They may be described using natural language or pseudocode

cancel (passenger P, flight F, date D)

if	there is some reservation for R seats for passenger P on flight F on date D
then	delete this reservation and decrease by R the number of seats reserved for flight F on date D
else	ignore the request and generate an error message
endif	

Axiomatic Specifications

- Operations can be specified as pairs of assertions capturing the relation between the data state before and after the operation

cancel (passenger P, flight F, date D)

precondition:

(1) R seats are reserved for passenger P on flight F on date D

(2) the total number of reserved seats for flight F on date D is K

postcondition:

(1) there are no reservations for passenger P on flight F on date D

(2) the number of reserved seats for flight F on date D is (K-R)

exception:

(1) an error message is displayed

Data Modeling

- Data modeling must emphasize information contents and simplicity, not design
- Any data modeling technique can be used
  - abstract variables
  - relations
  - entity-relation diagrams
  - objects
- Concept modeling (e.g., classes and inheritance) is helpful for complex systems

Abstract Variables

- The system state may be characterized by a set of components that represent information maintained by the system
- The domain of values assumed by such components should be application specific
- The representation should be abstract, mathematical forms are preferred

Abstract Variables

An airline reservation system

- Job queue—sequence of reservation and cancellation requests from travel agents

  (agent, action, passenger, flight number, date, number of sets)

- Schedule—set of flights

  (flight number, date, time, destination, capacity, bookings)

- Volume—counter of processed requests

Relations

- Relational models are particularly useful because of their intuitive appeal—they may be viewed as tables

Schedule

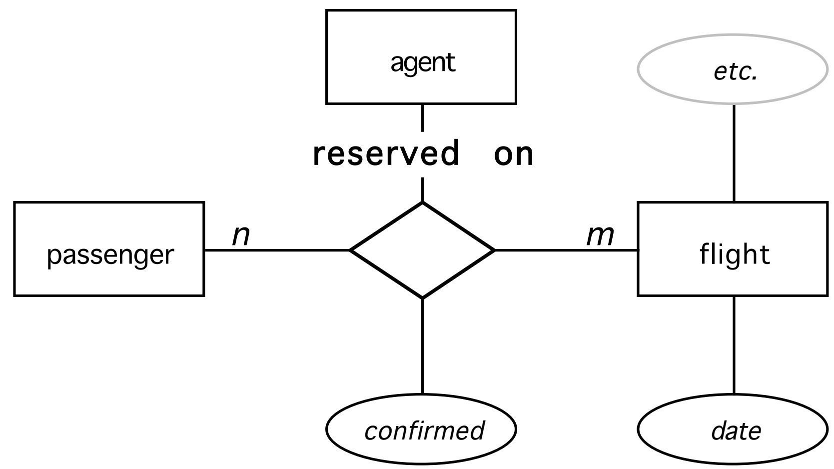
Flight	Date	Time	Dest.	Capacity	Booked
TW23	23-1-96	10:23	...	100	24
NW183	23-1-96	...	...	50	41
…	…	...	...	…	…

Reservations

Flight	Date	Name	Booked
TW23	23-1-96	Mary	1
TW23	23-1-96	Bob	3
TW23	23-1-96	Dana	1
…	…	…	…

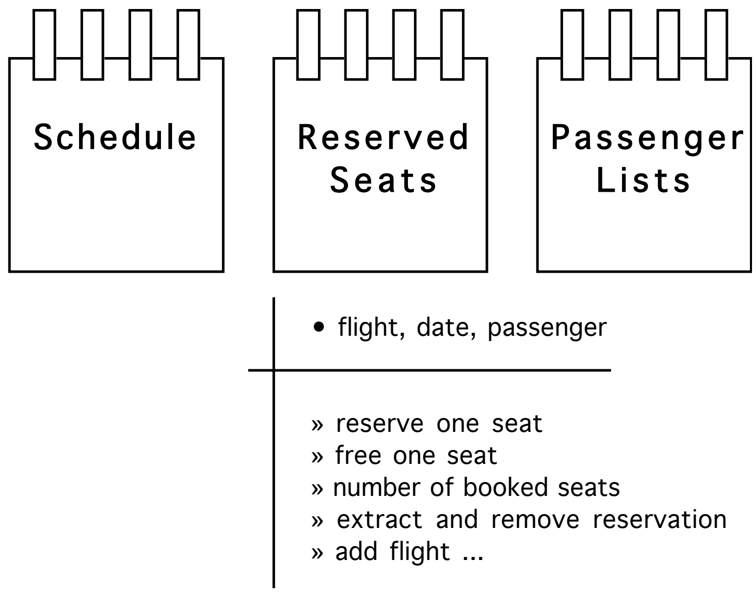
Entity-Relation Diagrams

- The approach has its roots in the database schema definition
- The key concepts are
  - entity set (contains entities)
  - relations over entity sets (may be recursive)
  - attributes (of entities and relations)



Objects

- Objects can be used to encapsulate data and common operations on it
- Objects are independent of each other
- Objects simplify the specification of the processing requirements



Integrity

- Semantic constraints capture important aspects of the application

    "reservations and cancellations involve only future flights"

- Local constraints can be tested by examining some data component in isolation

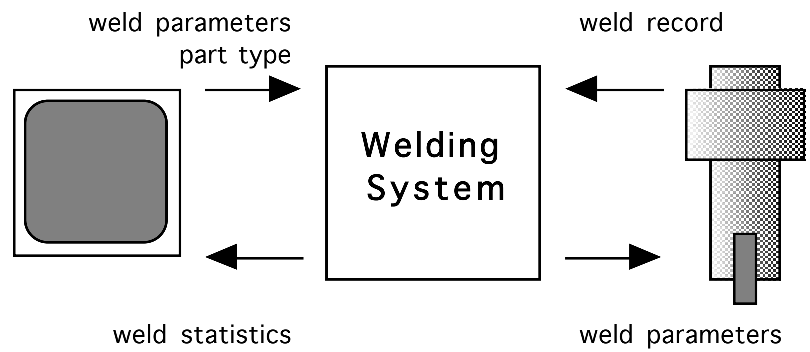
    "a flight has a single departure time for each individual date, if any"

- Global constraints involve relations among multiple components

    "the number of reserved seats cannot exceed the flight capacity plus the general overbooking factor"

Case Study: Welding

- Consider an automated welding tool used in the assembly of plastics in a medical application.
- Complete records must be maintained for each performed weld (e.g., duration, pressure, frequency).
- The goal is to be able to extract data about a specific part and to analyze failure patterns.



Case Study: Welding

- Data Model
  - Current part
  - Specifications
    - part number, duration, pressure, frequency
  - Statistics
    - part number, number of welds, number of failures
- Questions
  - Calibration, tolerances, etc.
- Operations
  - Work on part N
  - New welding record
  - Add part specification
  - Remove part specification
  - Display statistics
- Questions
  - Can modifications take place during welding?
  - How long are statistics kept?

6.5 Dataflow Model

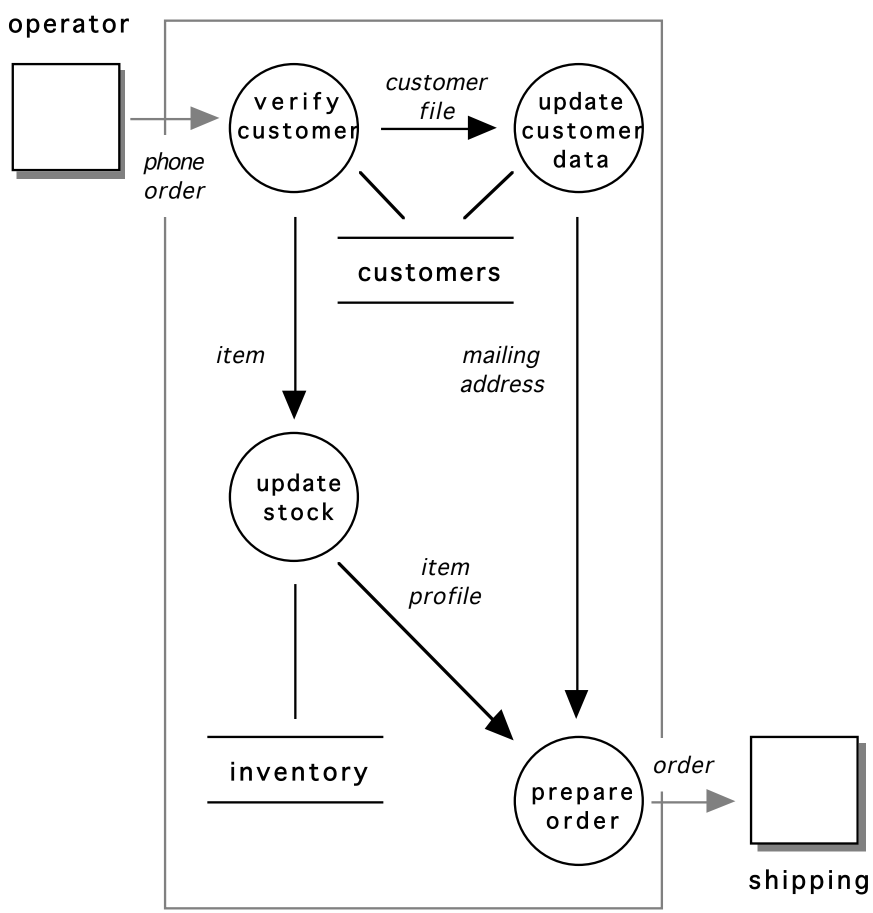
Process Control Applications

- Environment (abstract external interfaces)
  - inputs (data and events) are stimuli
  - outputs are externally visible responses
- System (software functionality)
  - the system maintains a certain amount of data
  - the system's response to inputs is a complex set of internal actions and external outputs

Model

- Dataflow diagrams notation
  - functions—deterministic input/output transformations triggered by the presence of all needed inputs
  - flows—unbounded queues
  - stores—global system data
  - terminators—interface models
  - minispecs—semantics of the lowest level functions
- Top-down functional decomposition provides a complexity control mechanism
- Data dictionary tracks the (global) names and their interpretation
- Execution model
  - fully concurrent interpretation
  - explicitly marked critical sections
  - stimulus/response interpretation

Notation


operator
phone
order
verify
customer
customer
file
update
customer
data
customers
item
mailing
address
update
stock
item
profile
inventory
prepare
order
order
shipping

Documentation

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3.1 Context diagram

- *system and its environment*
- *terminator definitions*

3.2 Dataflow diagrams

- *hierarchical decomposition of functions*
- *minispecs for lowest-level functions*

3.3 Data dictionary

- *flows and stores*

Critique

- Semantics of dataflow is often left undefined
  - atomicity (granularity of actions)
  - fairness (scheduling)
- Concurrent semantics are complex and may allow race conditions to occur
- The lack of minispecs for the high-level functions makes analysis and precise understanding difficult
- The diagrams are easy to understand only when the complexity is low, the development cost is high, and the communication bandwidth may be low
- Improper abstraction for the terminators leads to complex specifications

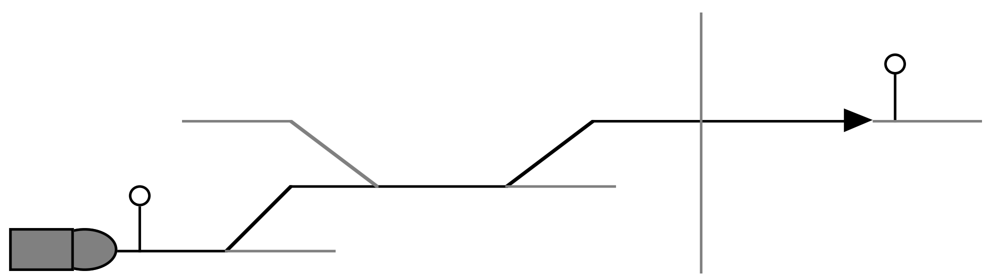
Complexity Control

- Hierarchical decomposition
- Horizontal partitioning

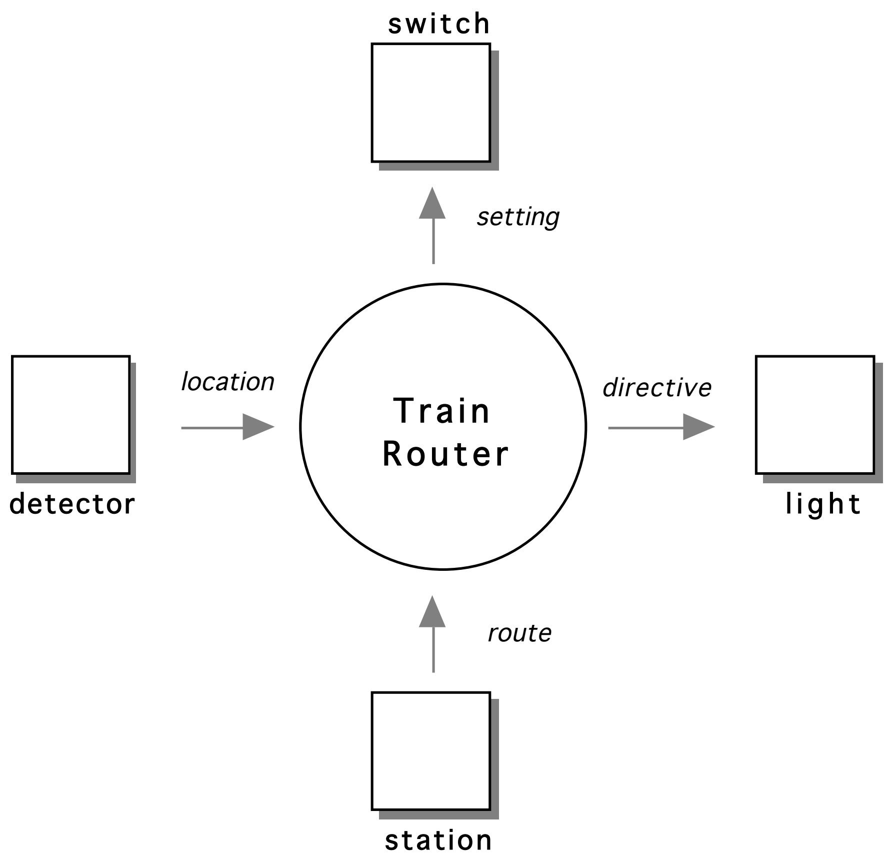
- Terminators can become abstract objects
- Stores can become abstract data objects
- Messages can become objects
- All objects may be instances of classes
- Classes may be defined in terms of each other by employing inheritance
- Inheritance and instance diagrams can by used to capture the relations among classes and objects

Case Study: Train Routing

- Consider a system designed to automatically route trains.
- Upon arrival at some light, the train is assigned a new route which takes it to the next light.
- The system selects the proper position for each switch along the route.



Case Study: Train Routing



Case Study: Train Routing

- Data stores
  - network layout
  - traffic
- Stimuli
  - arrival at a light
    - unlock side protection lights
    - identify blocked trains
    - reprocess their routes
    - get new route
    - lock side protection lights on red
    - turn light green (if successful)

6.6 User Manual

Applications Involving Human Interfaces

- Effective specifications often require the integration of multiple related models
- Human/computer interactions are too complex for commonly used requirements techniques
- The User Manual can be used as a substitute for large sections of the SRS

Documentation

1. Introduction
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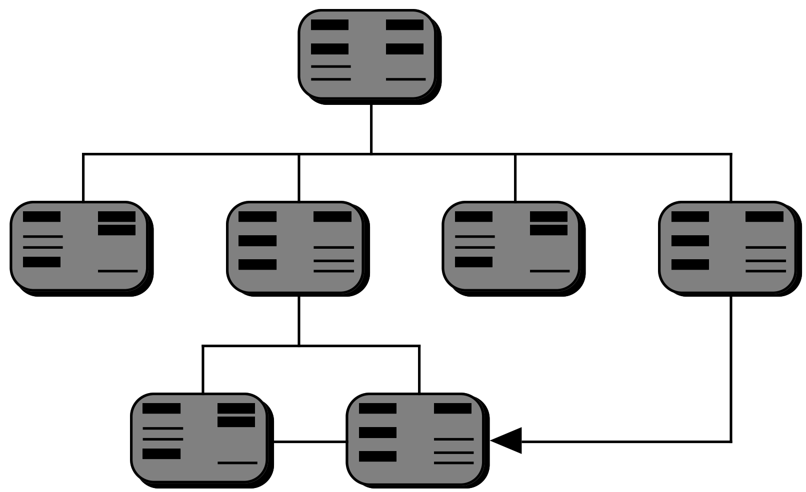
3. Specific requirements
   - *conceptual model*

   3.1 Navigation
   - *screen types and flow among them*
   - *common interactions*

   3.2 Screens
   - *layout and information contents*
   - *command semantics*

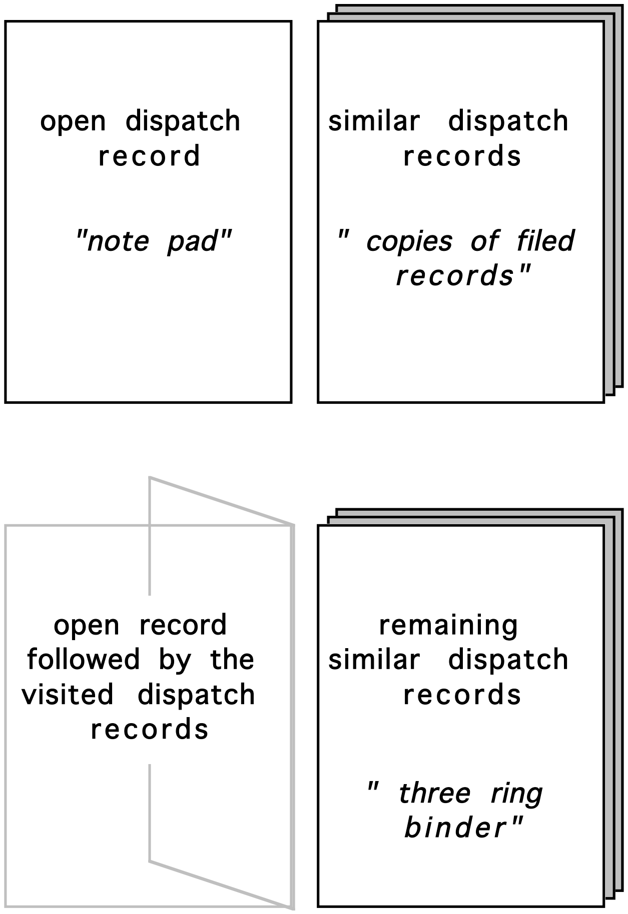
Navigation

- Identify the screens and the permissible transitions among them as a graph
- Identify the events that cause moves from one screen to another
- Identify interactions common among screens and specific to the user interface paradigm in use



Conceptual Model

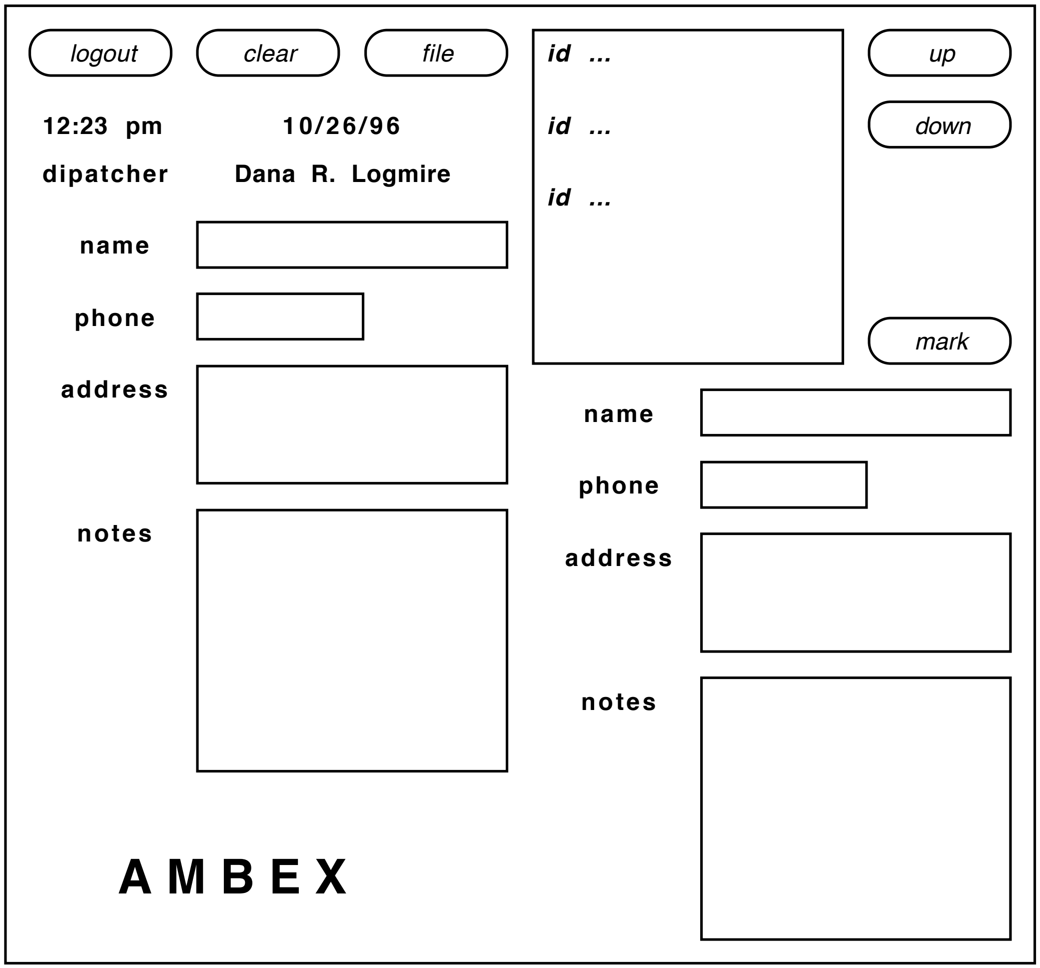
- The conceptual model is a mental map which helps the user anticipate correctly the expected system behavior (navigation, information, commands)
- Metaphors are effective tools for building conceptual models because the user can rely on previous experience



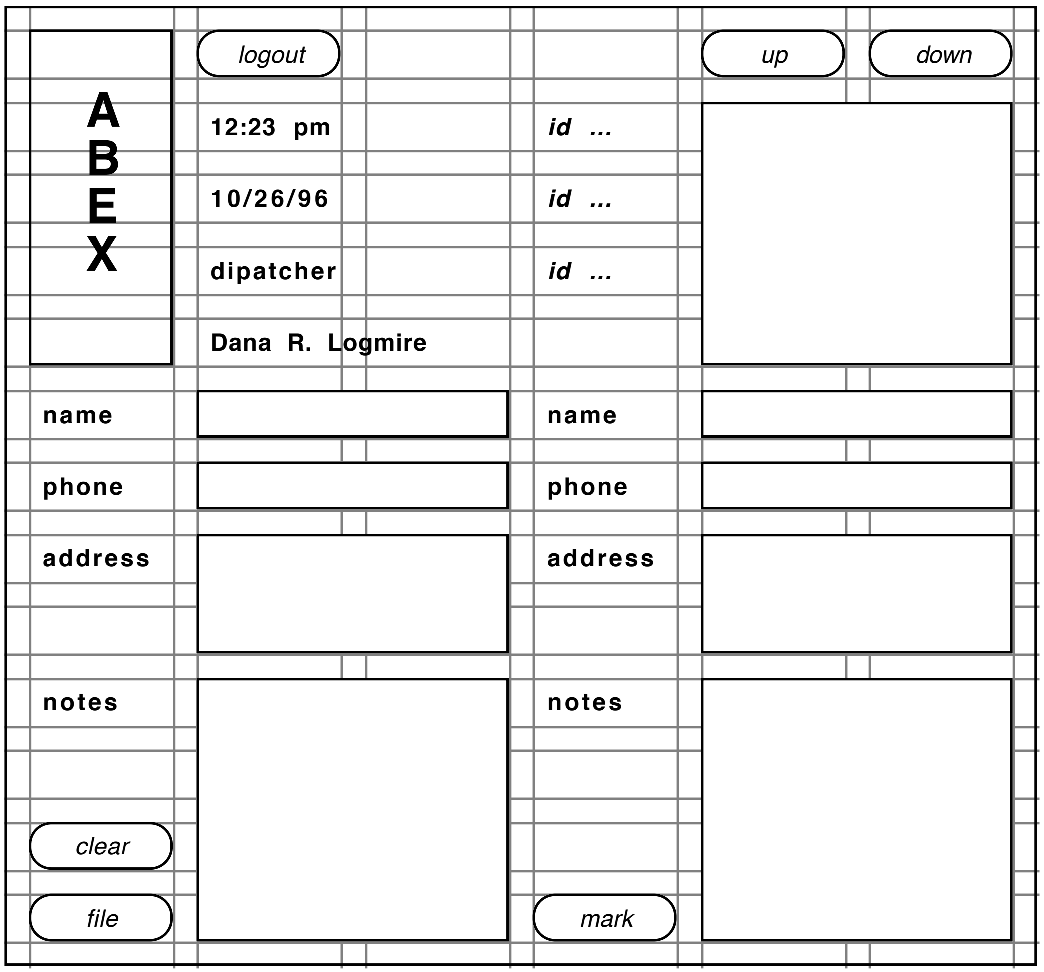
Screens

- Maximize readability (layout and structure)
  - simplicity
  - regularity of structure
  - minimality
- Minimize the potential for operator errors (interactions and general feel)
  - predictability
  - uniformity
  - forgiveness
- Optimize performance for the typical workflow
- Engineer each screen and the entire ensemble
  - grid-based design

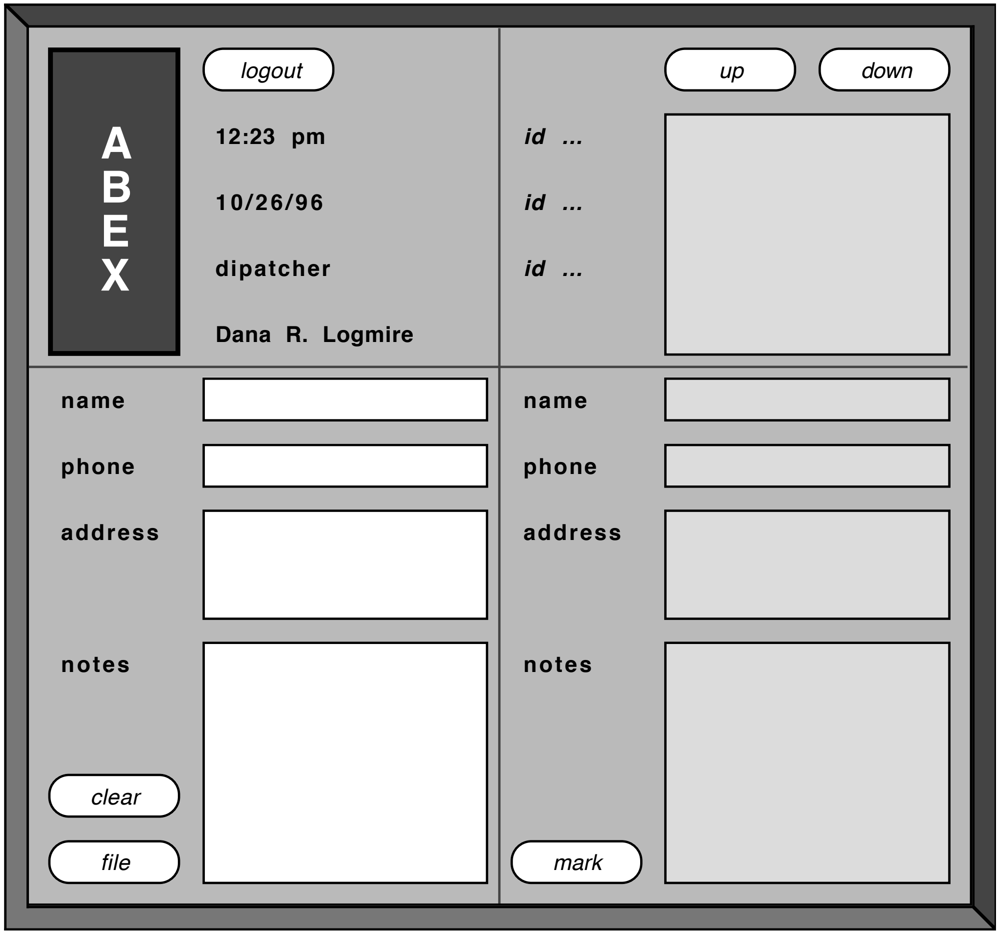
Ad-Hoc Solution



A Grid-based Design



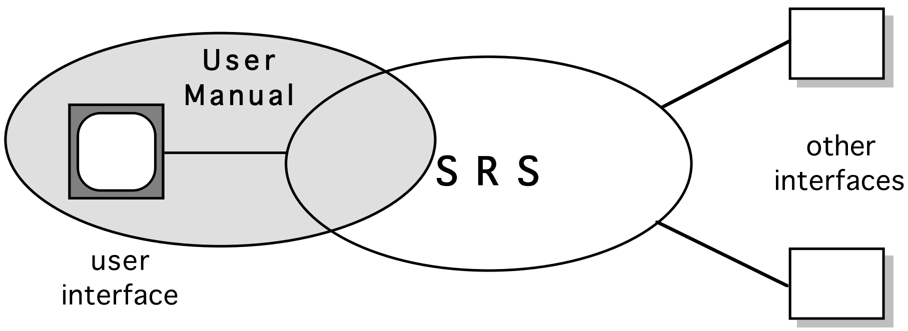
Final Design

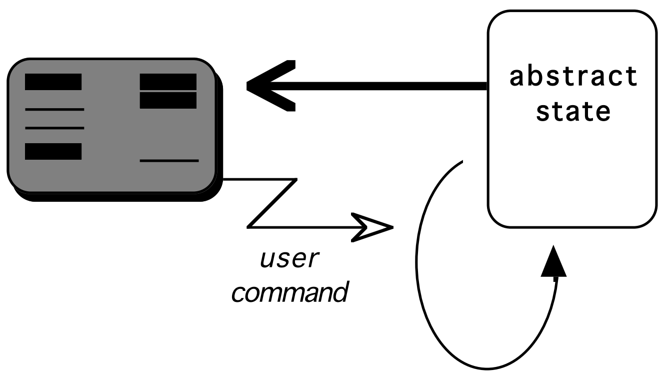


Multiple Models

- If the user manual cannot capture all functional aspects of the system two models are needed
- Consistency must be maintained
- The state representation should be that used in the SRS (common abstract state)
- User commands are specified only once as state transitions over the abstract state of the system
- State information needed for screen presentation is assumed to be directly available

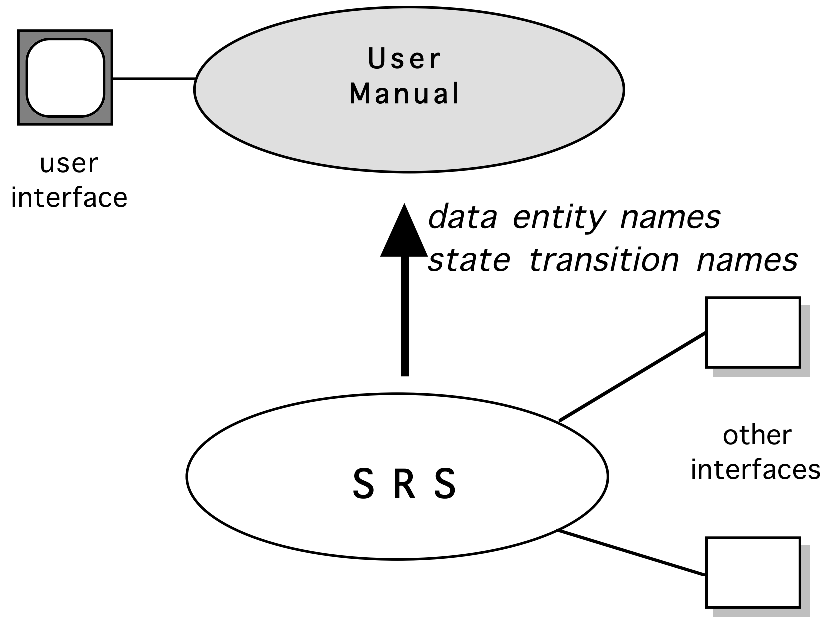
Multiple Models





Building on the SRS

- If most of the complexity in the user interface is due to the navigation and interaction pattern its development can be postponed until the SRS is completed
- Data and transition names can be used directly as in the SRS when needed



Case Study: Paint Drying

- Consider a controller for a paint drying application.
- Painted parts enter the oven one at a time.
- The control software ensures that the part is dried at the specified temperature for the specified duration before leaving the oven.
- The operator can override the duration or the dry cycle for custom parts.

- The system monitors duration and temperature settings and allows for changes in these settings.
- Only one setting is used at any one time.
- Production costs limit the interface to a simple display and two buttons.