Formal System Design Process with UML

Use a formal process & tools to facilitate and automate design steps:

Requirements
Specification
System architecture
Coding/chip design
Testing

Text: Chapter 1.4
Other resources on course web page.

Object-Oriented Design

- Describe system/design as interacting objects
  - Across multiple levels of abstraction
  - Visualize elements of a design
- Object = state + methods.
  - State defined by set of "attributes"
    - each object has its own identity.
    - user cannot access state directly
  - Methods (functions/operations) provide an abstract interface to the object attributes.
- Objects map to system HW/SW elements

Objects and classes

- Class: an object type that defines
  - state elements for all objects of this type.
    - Each object has its own state.
    - Elements not directly accessible from outside
    - State values may change over time.
  - methods (operations) used to interact with all objects of this type.
    - State elements accessed through methods

Object-oriented design principles

- Some objects closely correspond to real-world objects.
  - Other objects may be useful only for description or implementation.
- Abstraction: list only info needed for a given purpose
- Encapsulation: mask internal op's/info
  - Objects provide interfaces to read/write the object state.
  - Hide object's implementation from the rest of the system.
  - Use of object should not depend on how it's implemented

Unified Modeling Language (UML)

- Developed by Grady Booch et al.
  - Version 1.0 in 1997 (current version 2.4.1)
  - Maintained by Object Management Group (OMG) – www.omg.org
  - Resources (tutorials, tools): www.uml.org
- Goals:
  - object-oriented;
  - visual;
  - useful at many levels of abstraction;
  - usable for all aspects of design.
- Encourage design by successive refinement
  - Don't rethink at each level
  - CASE tools assist refinement/design

UML Elements

- Model elements
  - classes, objects, interfaces, components, use cases, etc.
- Relationships
  - associations, generalization, dependencies, etc.
- Diagrams
  - class diagrams, use case diagrams, interaction diagrams, etc.
  - constructed of model elements and relationships

Free/open source UML diagramming tools are available

Structural vs. Behavioral Models

- Structural: describe system components and relationships
  - *static* models
  - objects of various classes

- Behavioral: describe the behavior of the system, as it relates to the structure
  - *dynamic* models

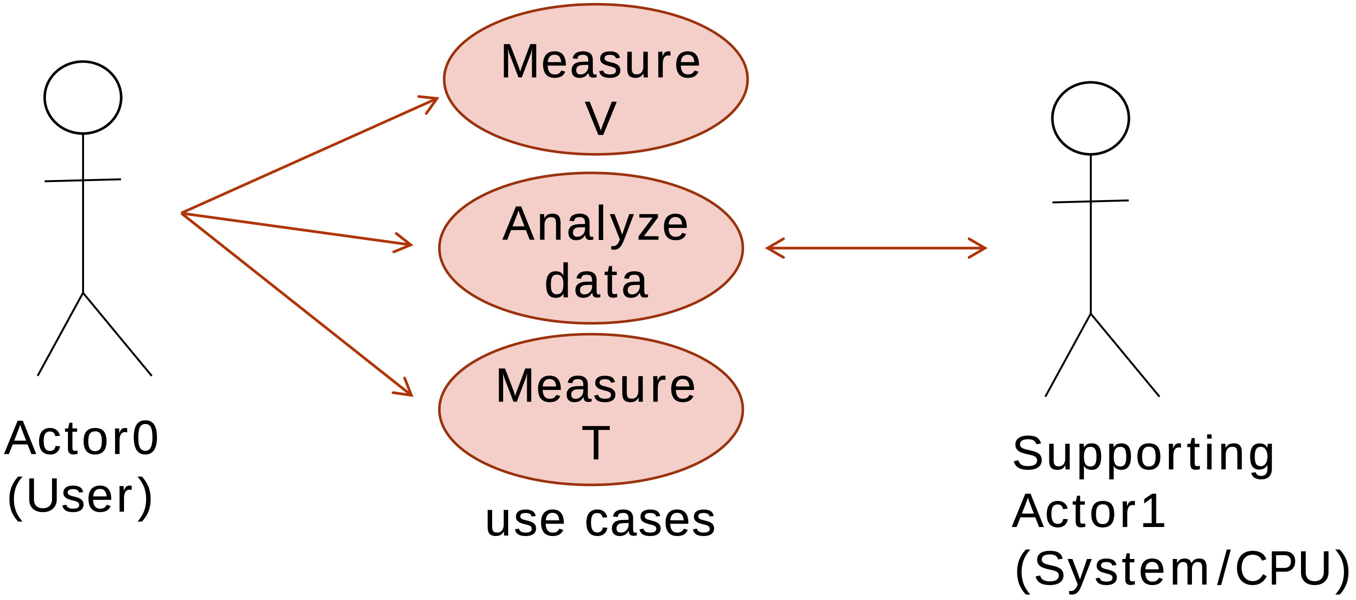
UML Diagram Types

- Use-case: help visualize functional requirements (user-system interaction)
- Class: types of objects & their relationships
- Object: specific instances of classes
- Interaction diagrams (dynamic)
  - Sequence: how sequences of events occur (message-driven)
  - Collaboration: focus on object roles
- Statechart: describe behavior of system/objects
- Component: physical view of system (code, HW)
- Others ….

UML *use case* diagrams

- Describe behavior user sees/expects (“what” – not “how”)
- Describe user interactions with system objects
- Users = actors (anyone/anything using the system)

Example: Data acquisition system

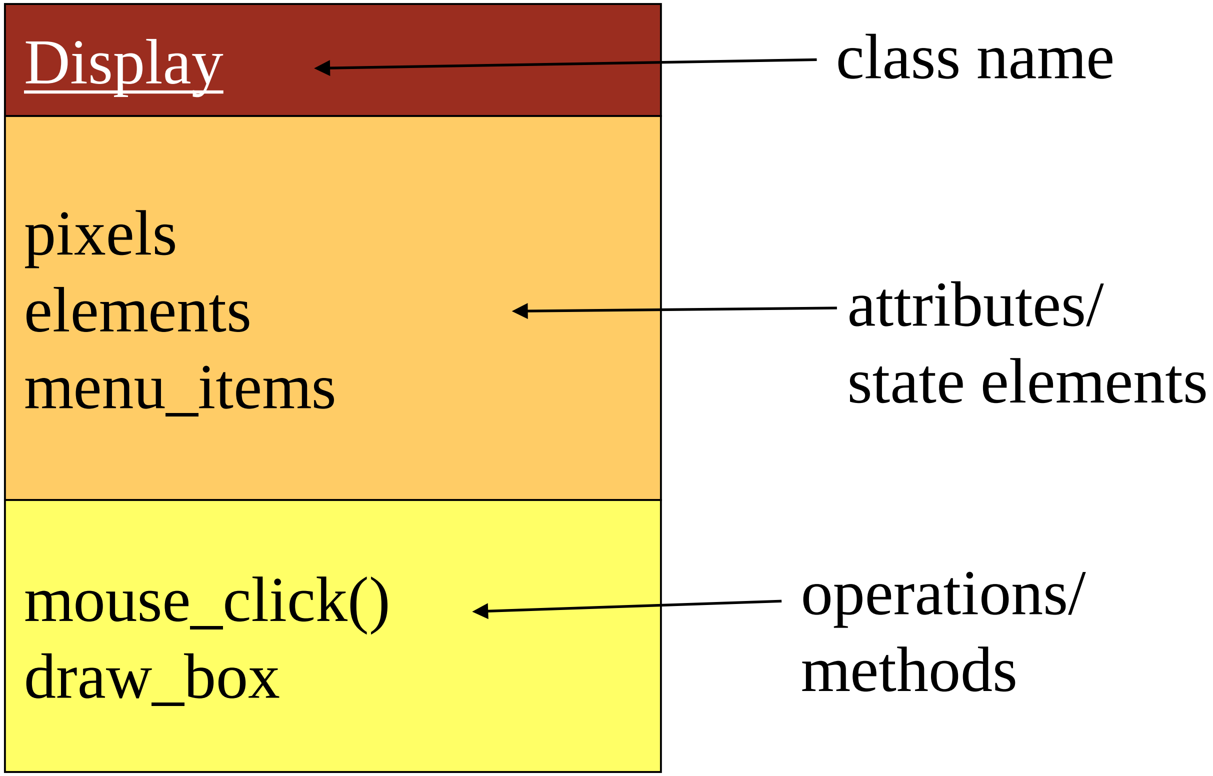


- Translate to algorithms for system design

DAQ system use case description

- **User**
  - Select measure volts mode
  - Select measurement range or autorange
- **System**
  - If range specified
    - Configure to specified gain
    - Make measurement
      - If in range – display results
      - If exceed range – display largest value and flash display
  - If auto range
    - Configure to midrange gain
    - Make measurement
      - If in range – display mode
      - If above/below range – adjust gain to next range and repeat
      - If exceed range – display largest value and flash display

UML class *(type of object)*



Display

pixels
elements
menu_items

mouse_click()
draw_box

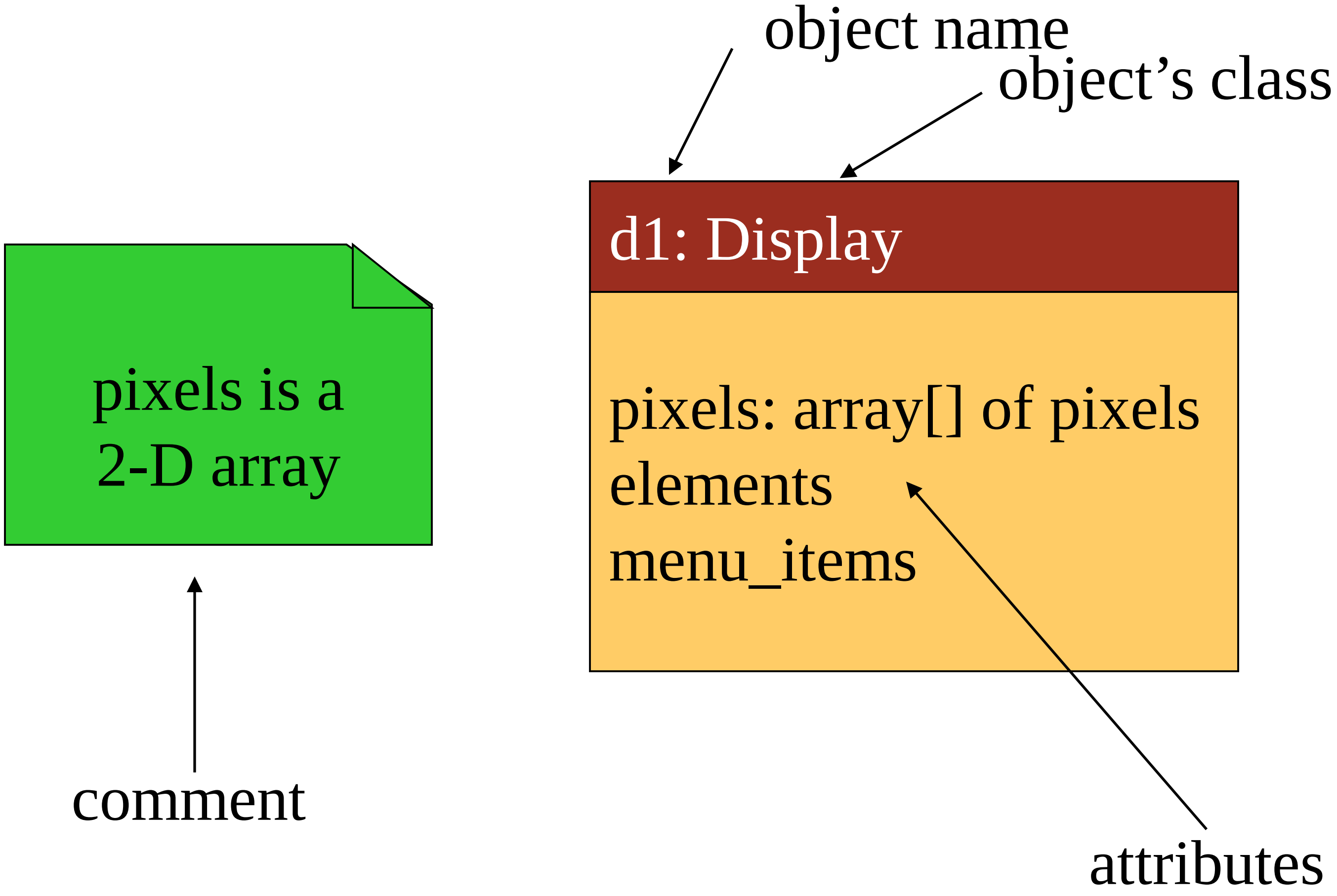
class name

attributes/
state elements

operations/
methods

Class diagram: shows relationships between classes

UML object



object name

object's class

d1: Display

pixels: array[] of pixels
elements
menu_items

pixels is a
2-D array

comment

attributes

Object diagram: static configuration of objects in a system

The class interface

- Encapsulation: implementation of the object is hidden by the class
  - **Interface**: How the user sees and interacts with the object
- Operations (methods) provide the abstract interface between the class' implementation and other classes.
  - An operation can examine/modify the object's state.
  - Operations may have arguments, return values.
- Often list only a subset of attributes/methods *within a given design context*
  - Those pertinent to that context

Choose your interface properly

- If the interface is too small/specialized:
  - object is *hard to use* for even one application;
  - even harder to *reuse*.

- If the interface is too large:
  - class becomes too *cumbersome* for designers to understand;
  - implementation may be too *slow*;
  - spec and implementation can be *buggy*.

Relationships between classes and objects

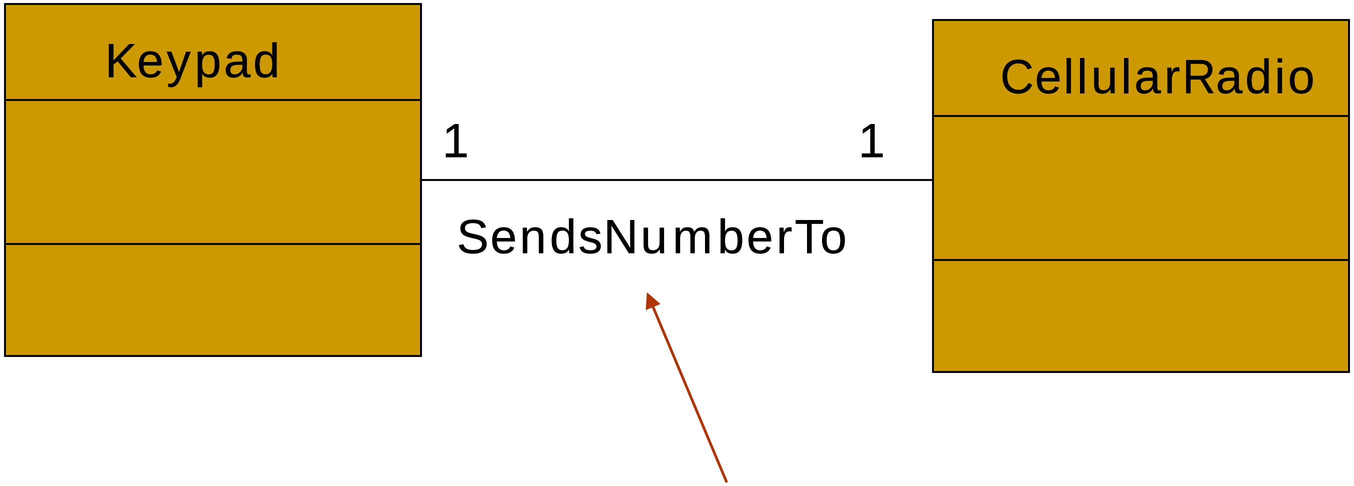
- Association: objects "related" but one does not own the other.

- Aggregation: complex object comprises several smaller objects.

- Composition: *strong* aggregation: part may belong to only one whole – deleting whole deletes parts.

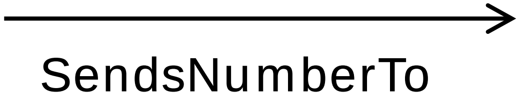
- Generalization: define one class in terms of another. Derived class inherits properties.

Association Example

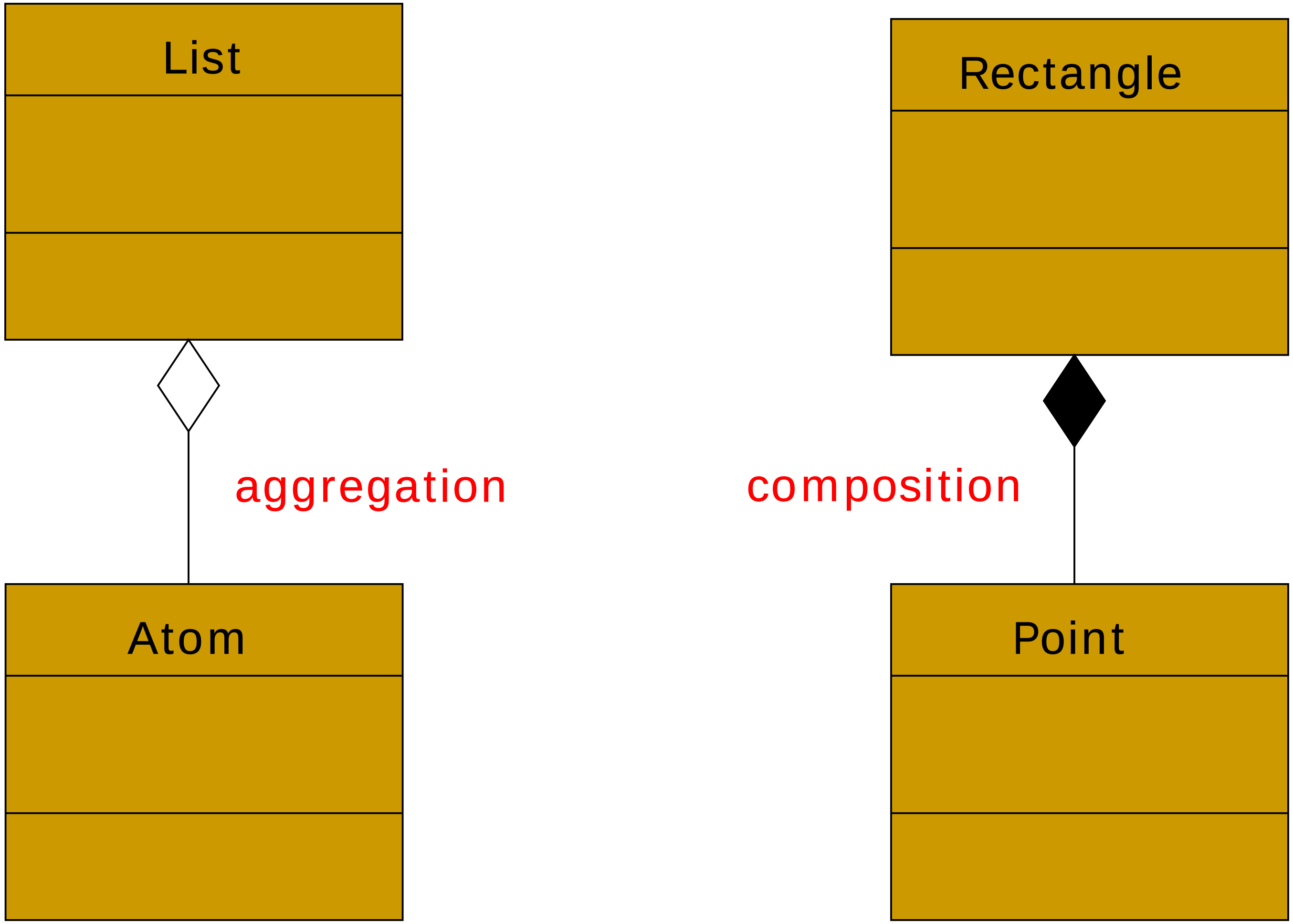


Nature of the association

Optionally – show “direction” of association



Aggregation/Composition Examples



List

aggregation

Atom

Rectangle

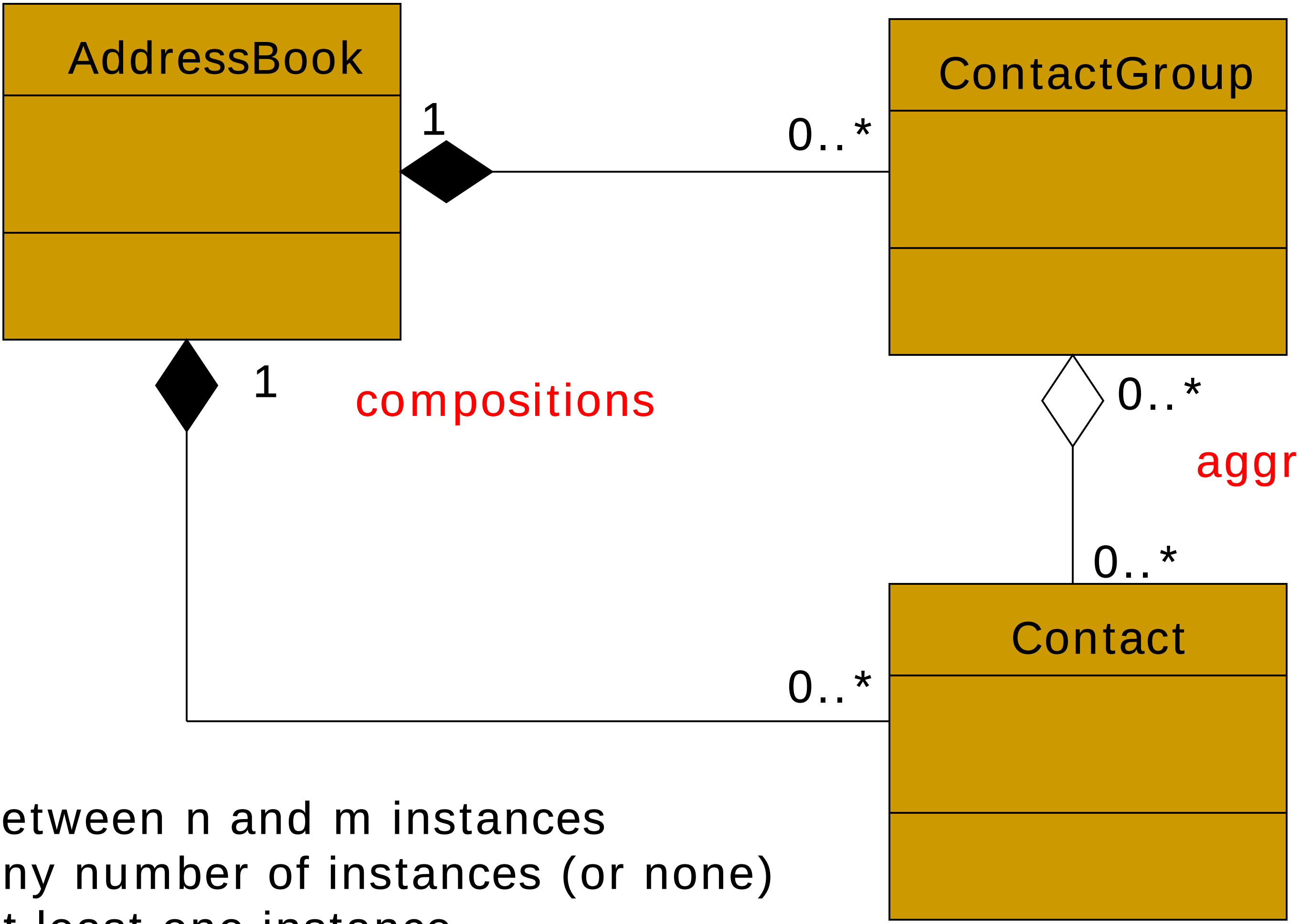
composition

Point

Atoms may be in other lists
Deleting list doesn’t delete atoms.

Points can only be on one rectangle
Deleting rectangle deletes points.

Aggregation/Composition Examples



AddressBook

ContactGroup

Contact

1

0..*

1

0..*

0..*

0..*

compositions

aggregation

n..m - between n and m instances

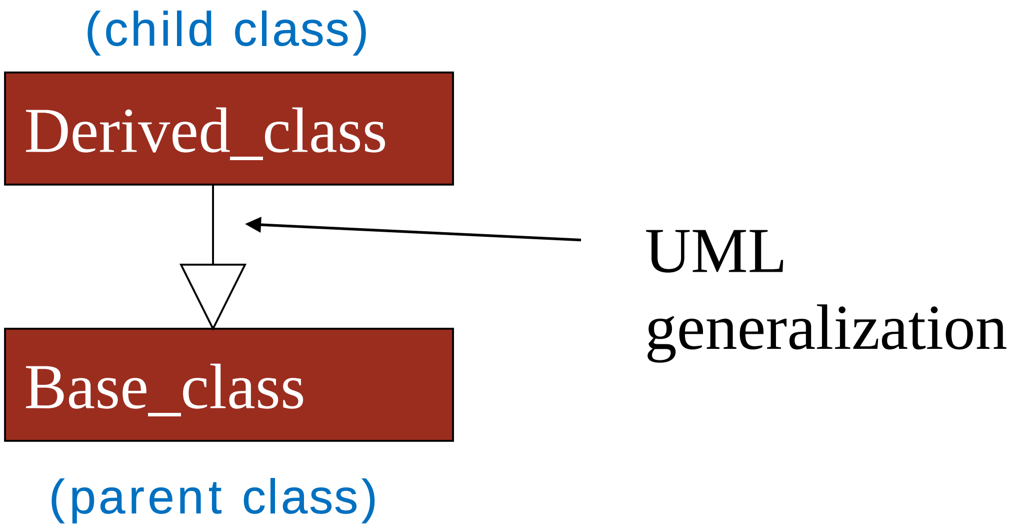
0..* - any number of instances (or none)

1..* - at least one instance

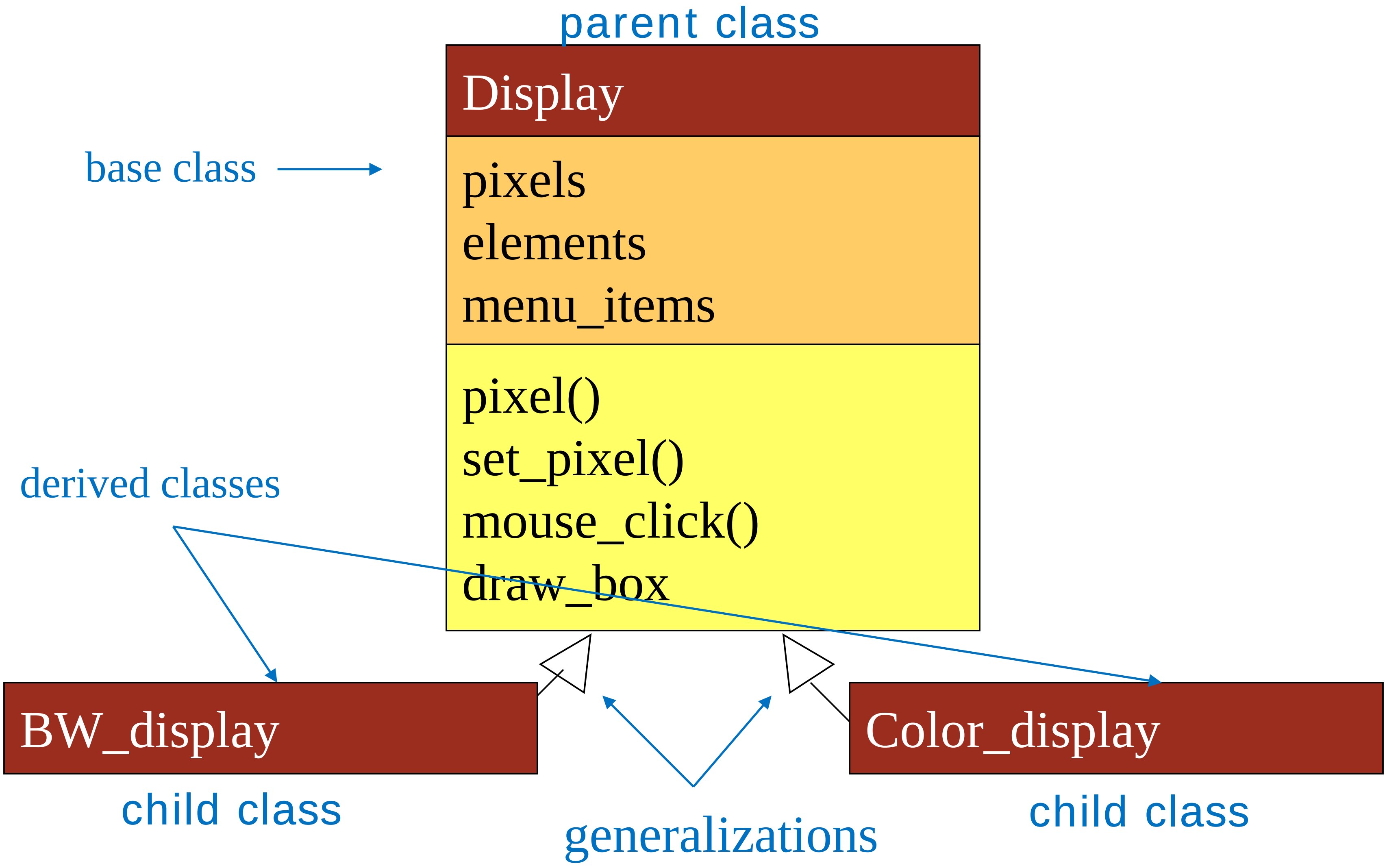
1 - exactly one instance

Generalization/Class derivation

- May define one class in terms of another (more "general") class.
  - Instead of creating a new class
- Derived class inherits attributes & operations of base class.



Class derivation example



parent class

base class

Display

pixels
elements
menu_items

pixel()
set_pixel()
mouse_click()
draw_box

derived classes

BW_display

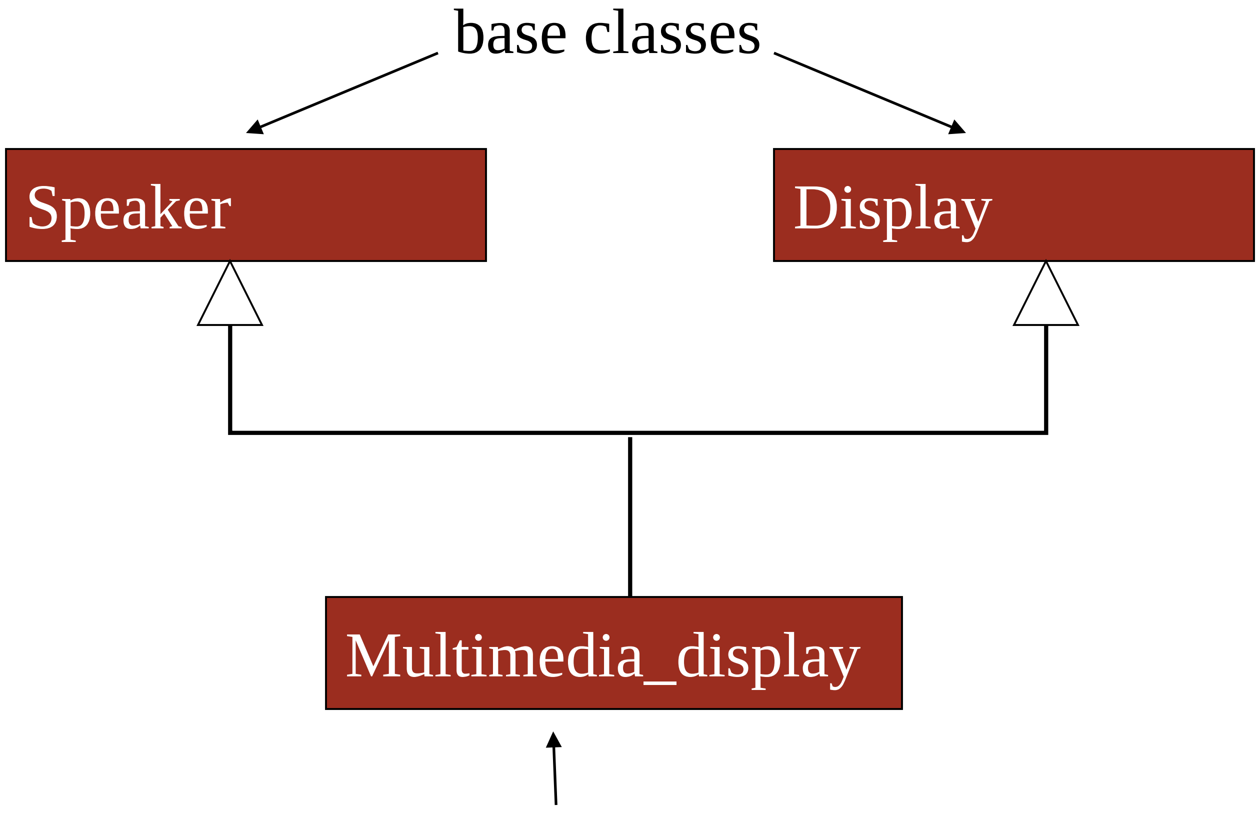
child class

Color_display

child class

generalizations

Multiple inheritance



base classes

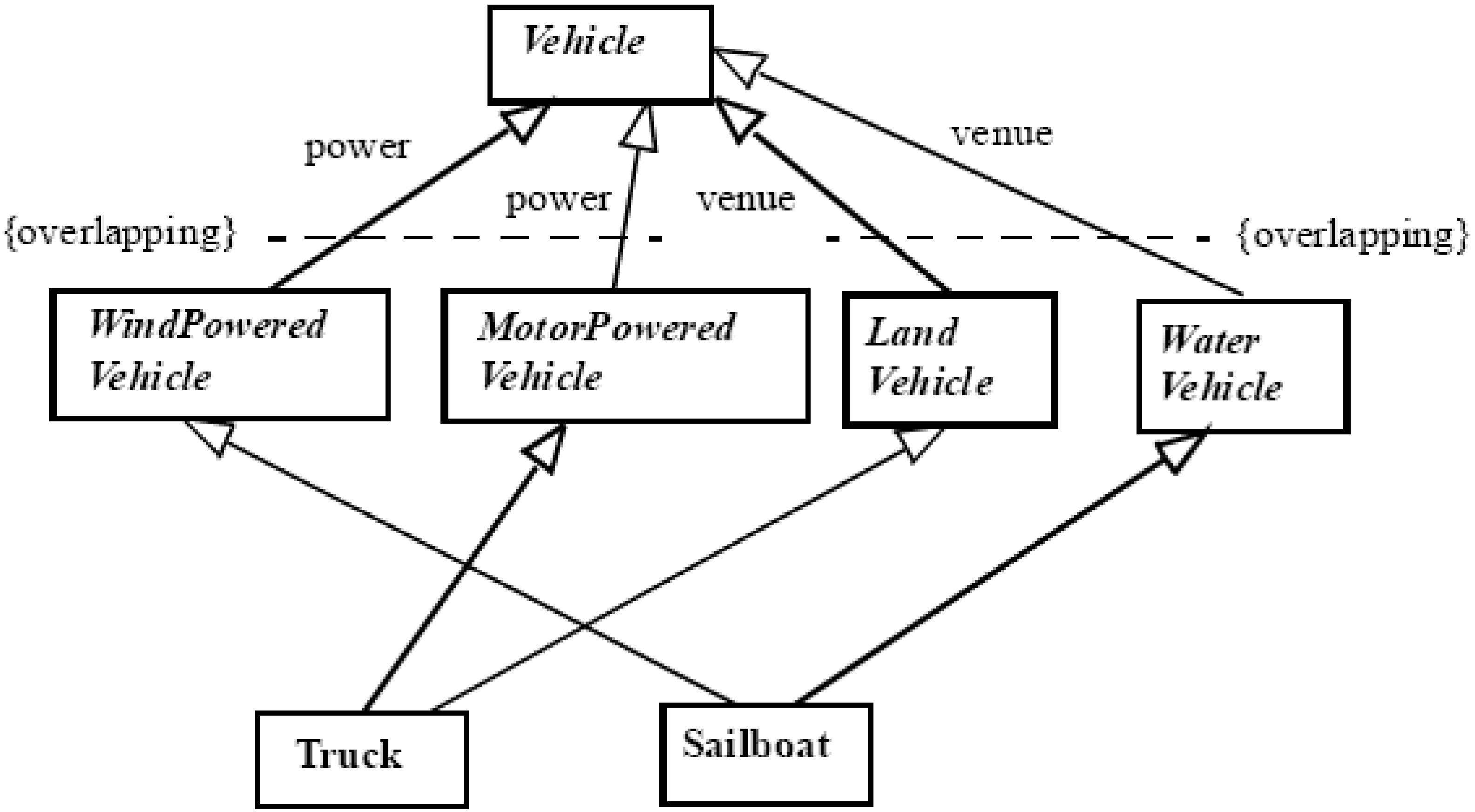
Speaker

Display

Multimedia_display

derived class inherits properties of **both** base classes

Generalization example



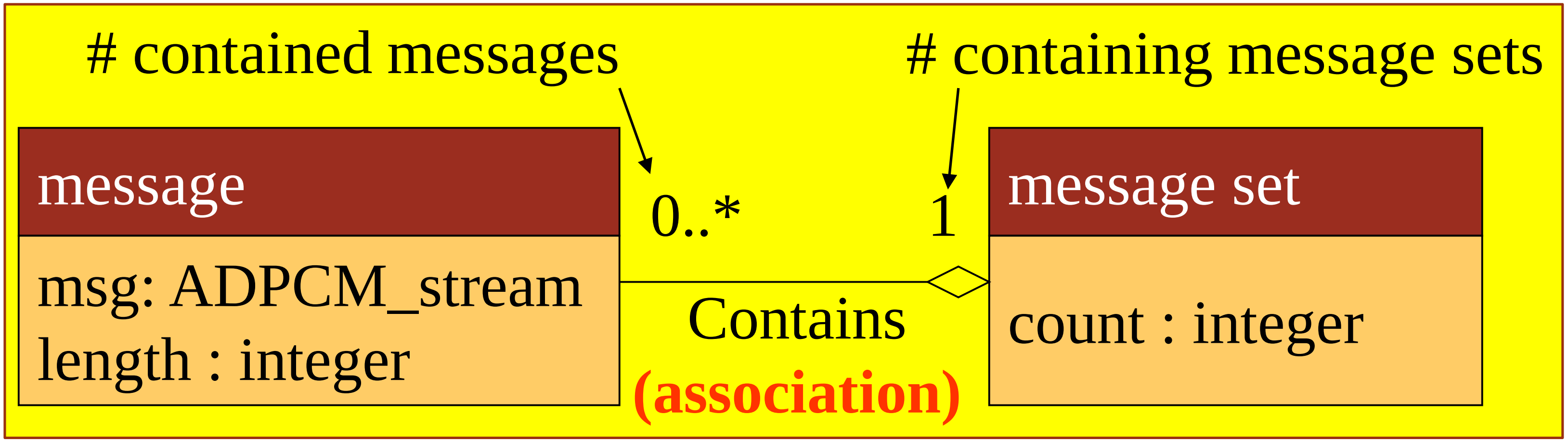
Links and associations

- Association: describes relationship between classes.
  - Association & class = abstract

- Link: describes relationships between objects.
  - Link & object = physical

Association & link examples

Class Diagram



contained messages

containing message sets

message

msg: ADPCM_stream

length : integer

0..*

1

Contains

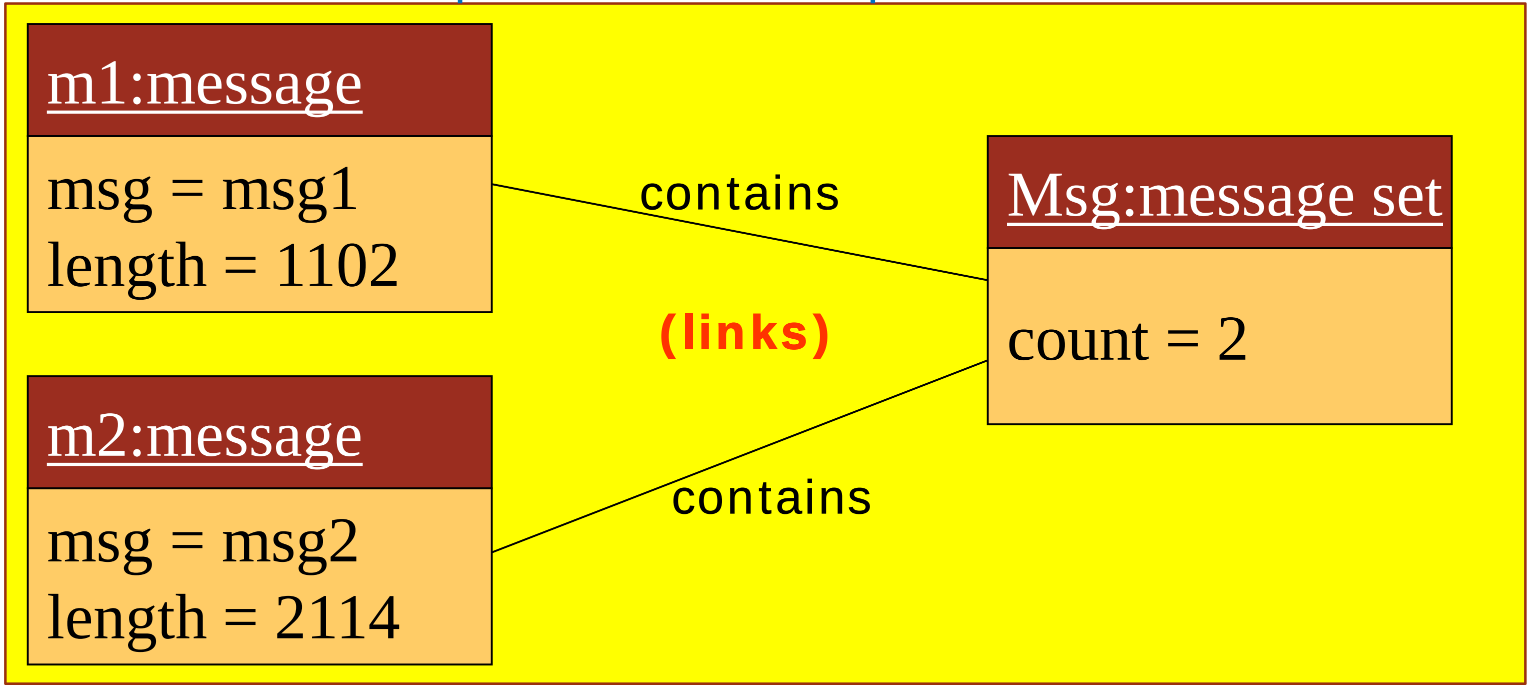
(association)

message set

count : integer

ADPCM: adaptive differential pulse-code modulation

Object Diagram



m1:message

msg = msg1

length = 1102

contains

Msg:message set

count = 2

(links)

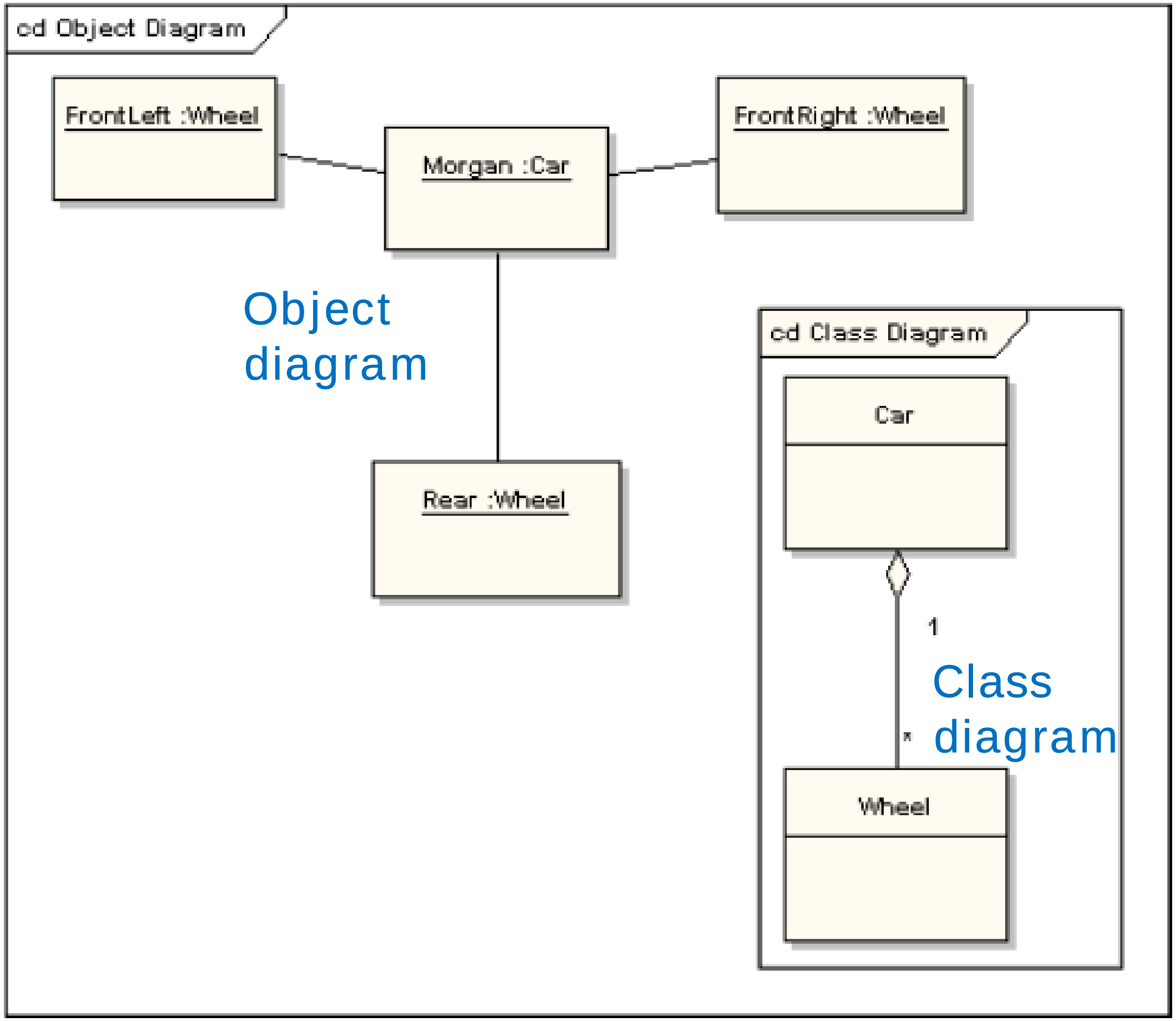
m2:message

msg = msg2

length = 2114

contains

Object & Class Diagram Example



Object diagram

Class diagram

OO implementation in C++

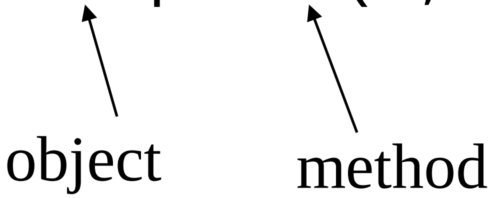
(derive from UML diagram)

```
/* Define the Display class */
class Display {
  pixels : pixeltype[IMAX,JMAX]; /* attributes */
public:
  /* methods */
  Display() { }  /* create instance */
  pixeltype pixel(int i, int j) {
       return pixels[i,j]; }
  void set_pixel(pixeltype val, int i,
       int j) { pixels[i,j] = val; }
}
```

Instantiating an object of a class in C++

```
/*instantiate Display object d1*/
Display d1;

/* manipulate object d1 */
apixel = d1.pixel(0,0);
```



object

method

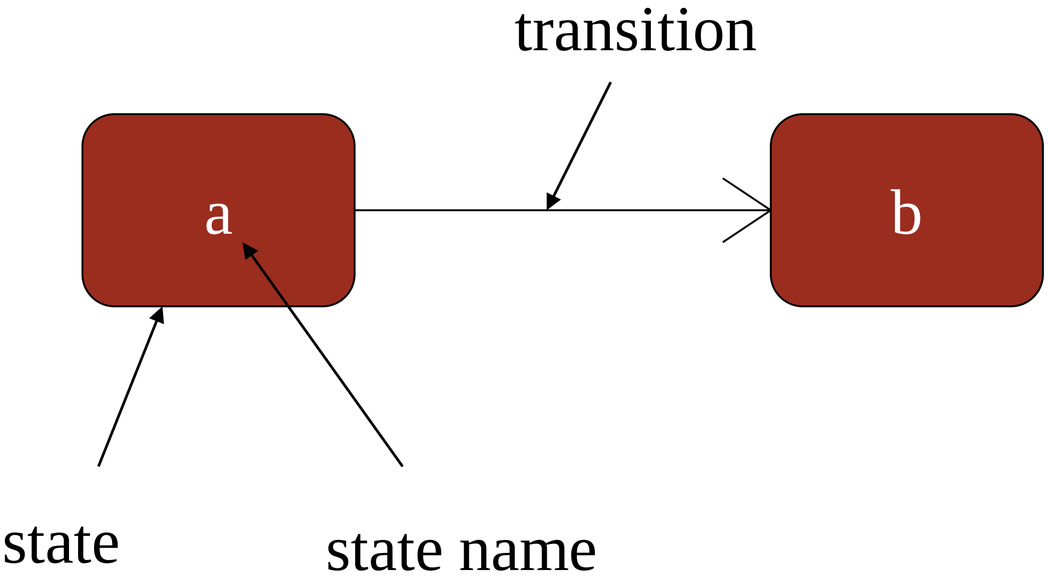
```
d1.set_pixel(green,18,123);
```

Behavioral descriptions

- Several ways to describe behavior:
  - internal view;
  - external view.
- Dynamic models:
  - State diagram: state-dependent responses to events
  - Sequence diagram: message flow between objects over <u>time</u>
  - Collaboration diagram: relationships between objects
- Specify:
  - inter-module interactions
  - order of task executions
  - what can be done in parallel
  - alternate execution paths
  - when tasks active/inactive

State machines

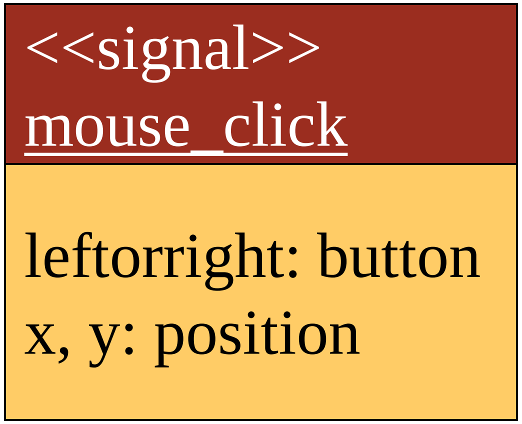
Similar to sequential circuit state diagrams



Event-driven state machines

- Behavioral descriptions are written as event-driven state machines.
  - Machine changes state on occurrence of an “event”.
- An *event* may come from inside or outside of the system.
  - Signal: asynchronous event.
  - Call: synchronized communication.
  - Timer: activated by time.
- May also have state changes without events
  - Ex. when some condition is satisfied

Signal event



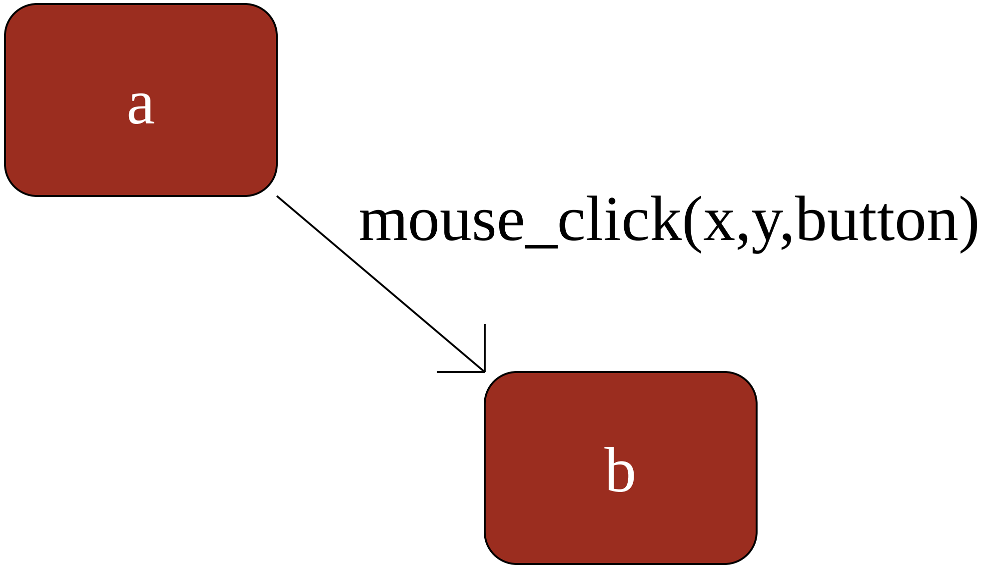
<<signal>>

mouse_click

leftorright: button

x, y: position

event declaration



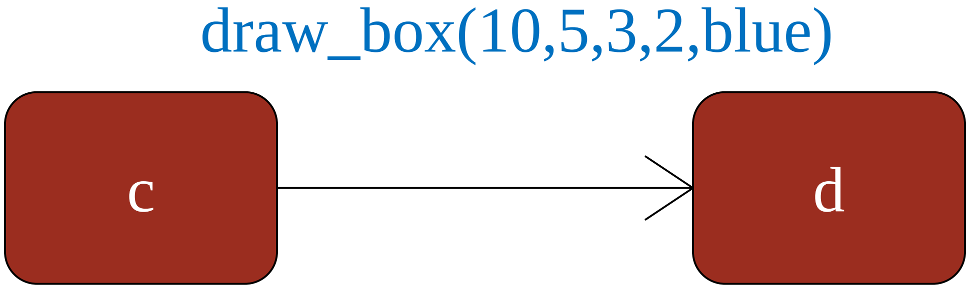
a

mouse_click(x,y,button)

b

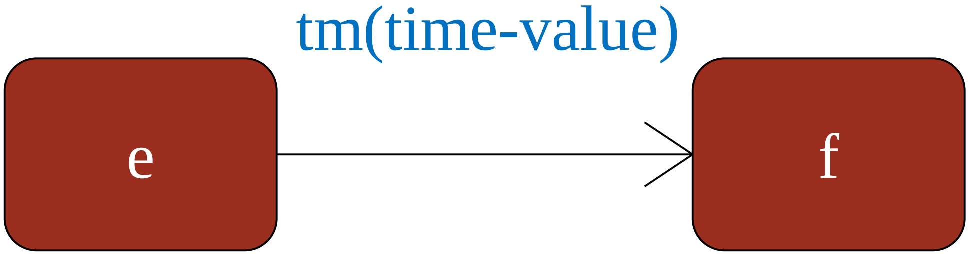
event description

Call event



draw_box(10,5,3,2,blue)

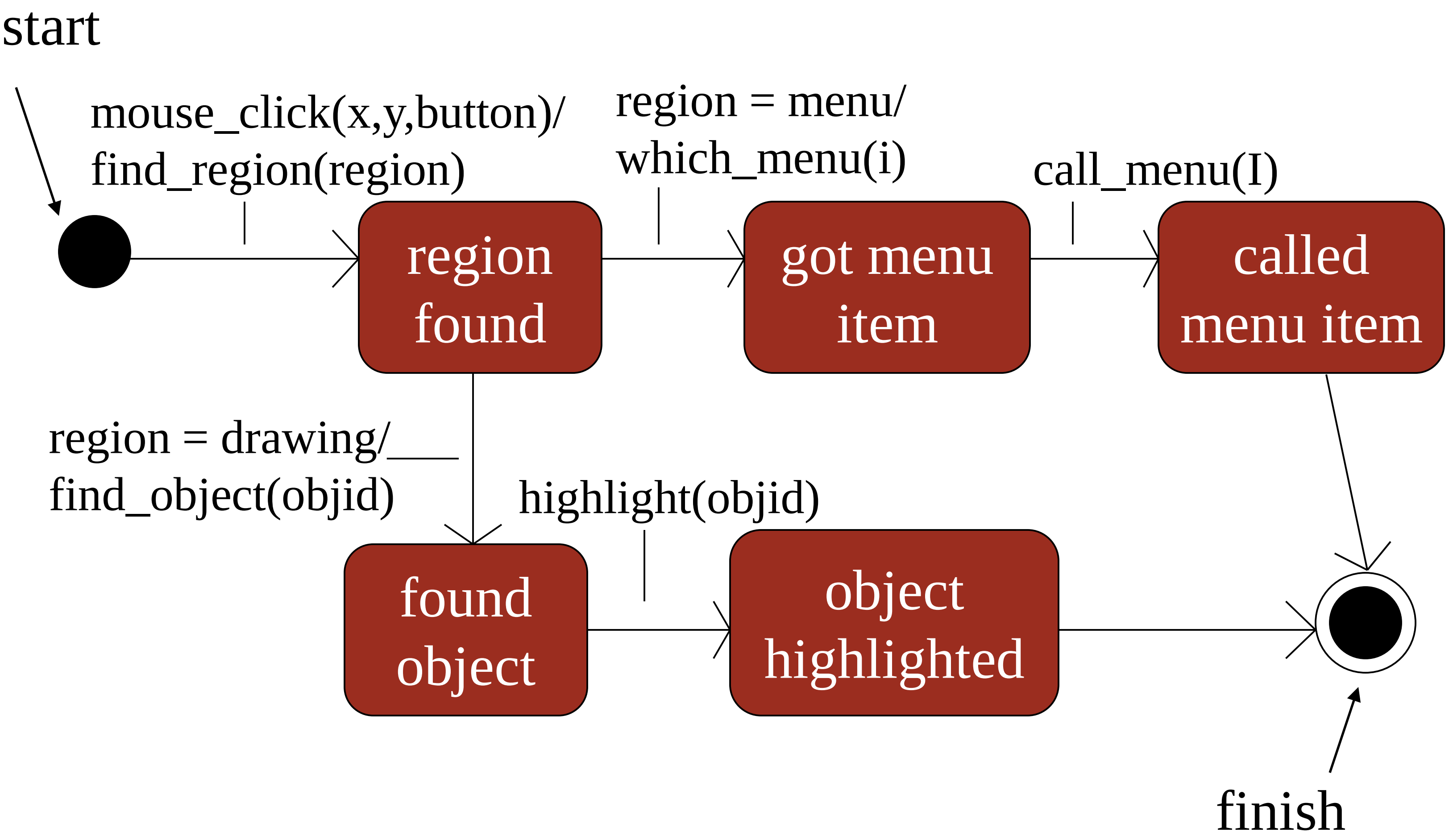
Timer event



tm(time-value)

Ex. RTOS “system tick timer”

Example: click on a display



start

mouse_click(x,y,button)/
find_region(region)

region found

region = menu/
which_menu(i)

got menu item

call_menu(I)

called menu item

region = drawing/
find_object(objid)

found object

highlight(objid)

object highlighted

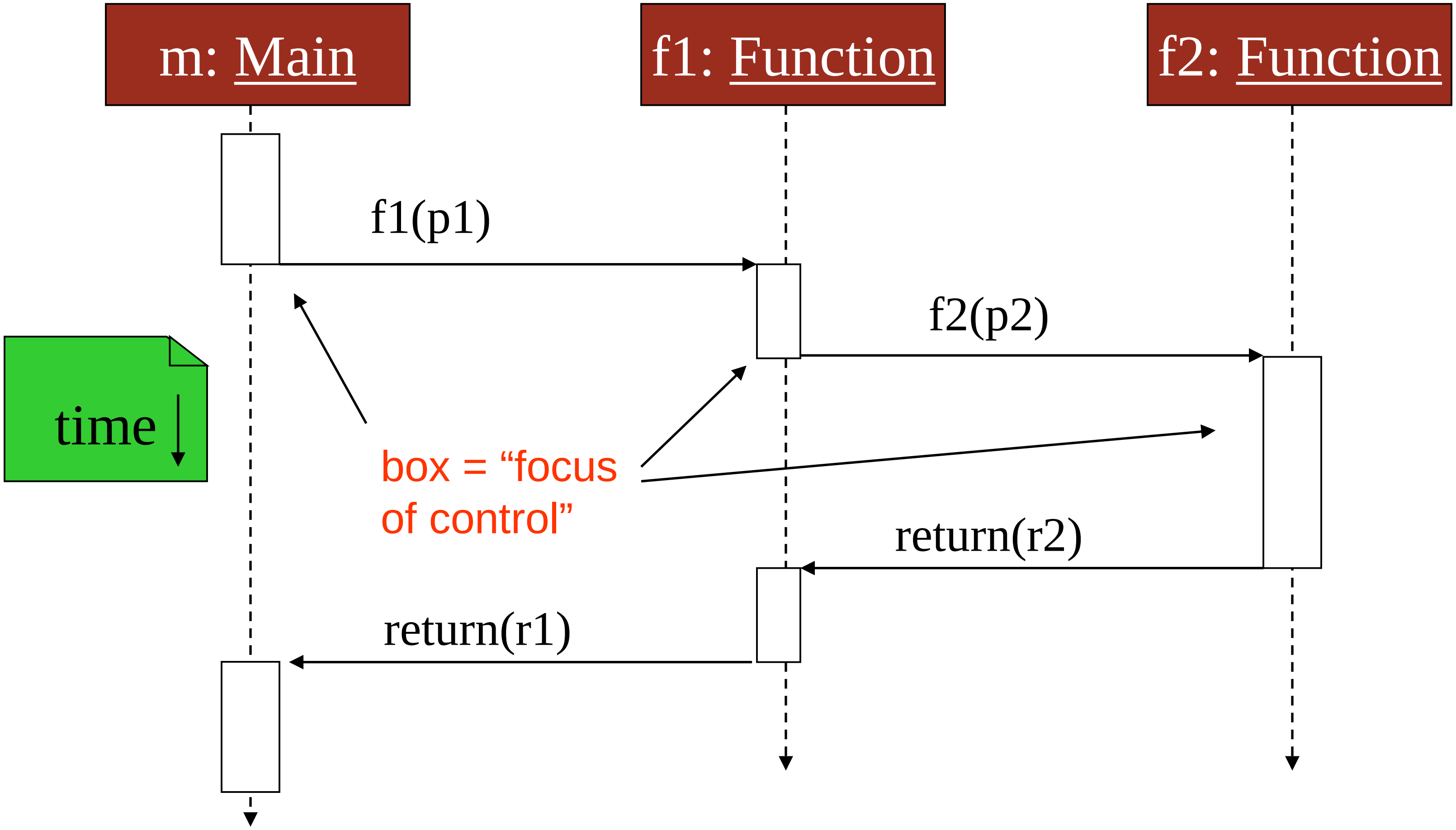
finish

Sequence diagram

- Shows sequence of operations over time.
  - Use to plan timing of operations
  - Relates behaviors of multiple objects.
- Objects listed at top from left to right
  - Each object has a time line (shown as dashed line)
  - Focus of control (shown as a rectangle) indicates when object is "active"
  - Actions between objects shown as horizontal lines/arrows

Sequence diagram example

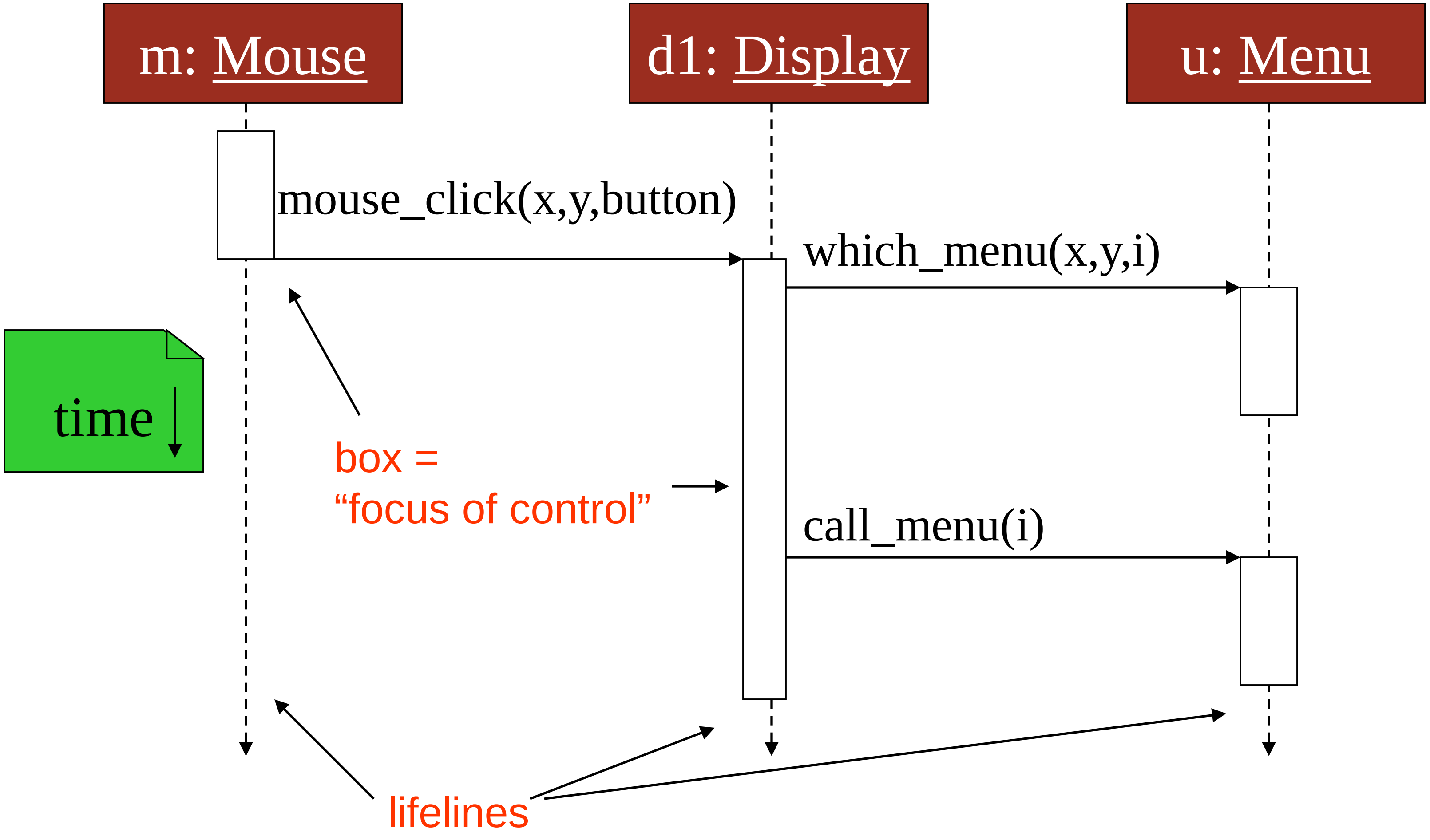
Programs on a CPU: only one has control of CPU at a time



box = "focus of control"

Sequence diagram example

Display and menu co-exist (both “active”)



m: Mouse

d1: Display

u: Menu

mouse_click(x,y,button)

which_menu(x,y,i)

call_menu(i)

time

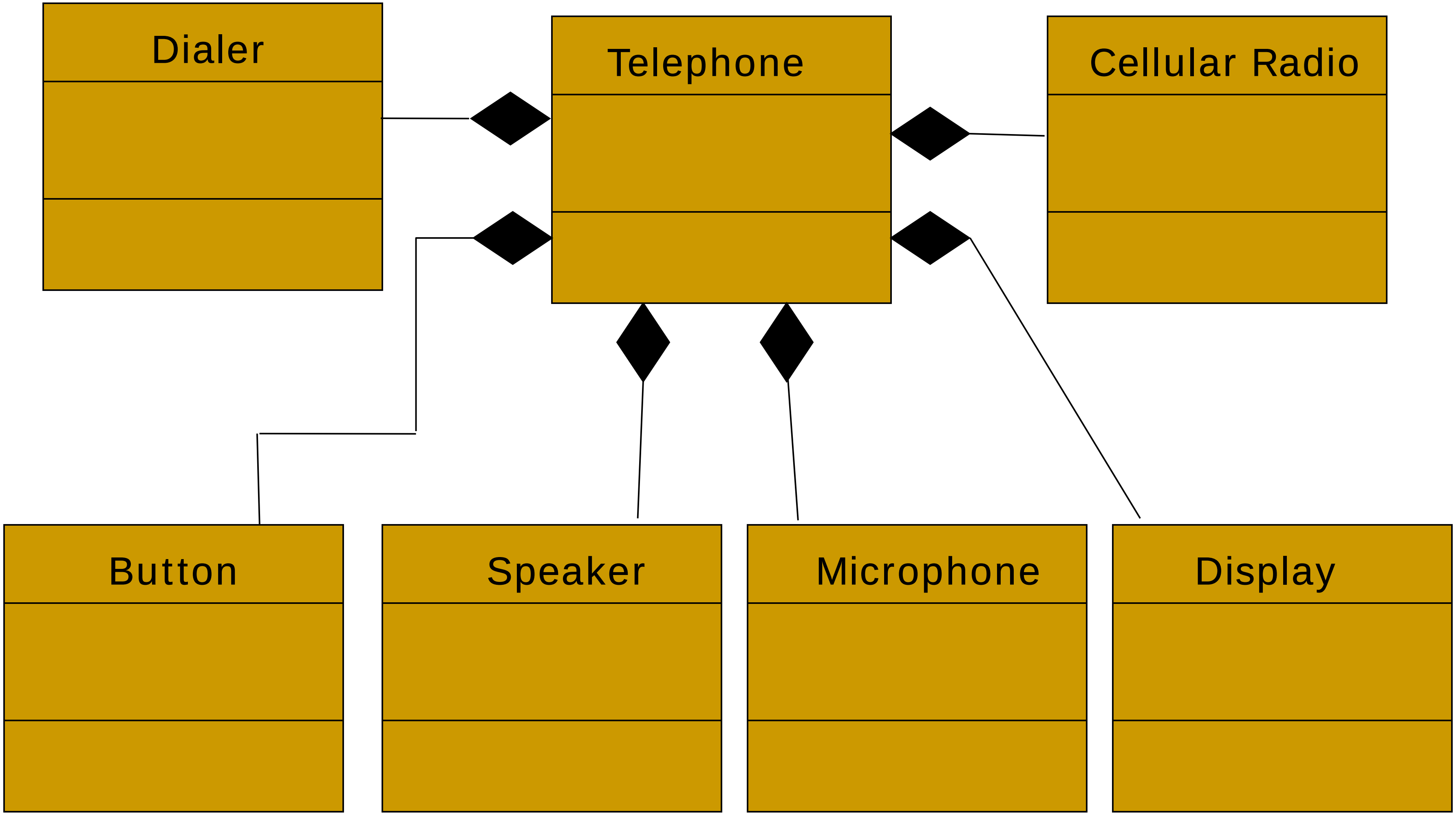
box =
“focus of control”

lifelines

Collaboration Diagram

- Show relationship between object in terms of messages passed between them
  - Objects as icons
  - Messages as arrows
  - Arrows labeled with sequence numbers to show order of events

Example: Cell phone class diagram



Source: Robert C. Martin, “UML Tutorial: Collaboration Diagrams”

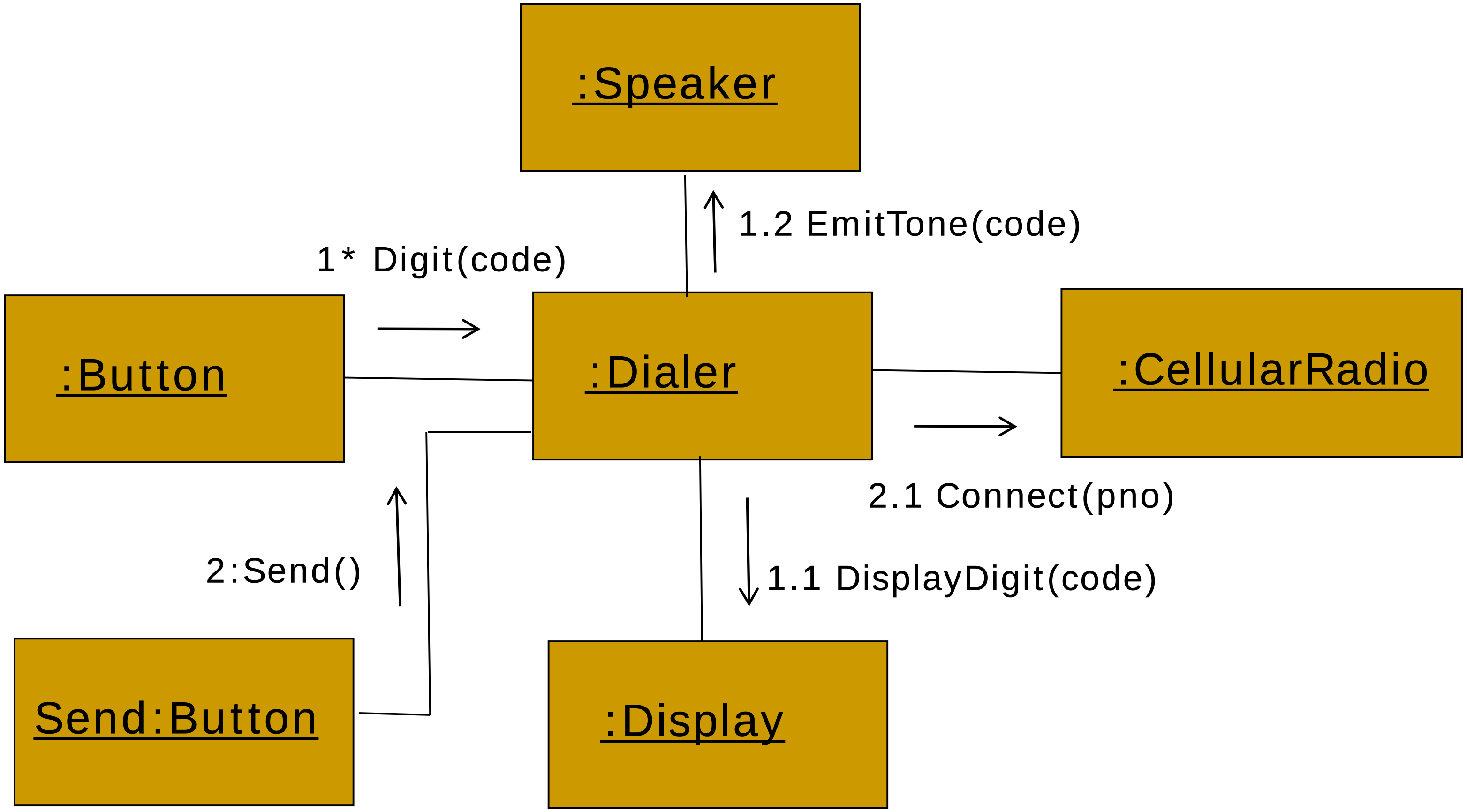
Cell phone use case: Make call

1. User enters number (presses buttons)
2. Update display with digits
3. Dialer generates tones for digits – emit from speaker
4. User presses "send"
5. "In use" indicator lights on display
6. Cell radio connects to network
7. Digits sent to network
8. Connection made to called party

Source: Robert C. Martin, "UML Tutorial: Collaboration Diagrams"

Collaboration diagram: Make call

Show collaborations in the previous use case (including order)



Source: Robert C. Martin, “UML Tutorial: Collaboration Diagrams”

Summary

- Example: Model train set (Section 1.4)

- Object-oriented design helps us organize a design.
- UML is a transportable system design language.
    - Provides structural and behavioral description primitives.