The role of abstractions

- Procedural abstractions
- Data abstractions

Goal: treat complex things as primitives, and hide details

- Questions:
  - How easy is it to break system into abstraction modules?
  - How easy is it to extend the system?
    - Adding new data types?
    - Adding new methods?

One View of Data

- Tagged data:
  - Some complex structure constructed from cons cells
  - Explicit tags to keep track of data types
  - Implement a data abstraction as set of procedures that *operate* on the data

	Data type 1	Data type 2	Data type 3	Data type 4
Operation 1	Some proc	Some proc	Some proc	Some proc
Operation 2	Some proc	Some proc	Some proc	Some proc
Operation 3	Some proc	Some proc	Some proc	Some proc
Operation 4	Some proc	Some proc	Some proc	Some proc

Factoring Operation/Type Association

- "Generic" operations by looking at types:

```
(define (scale x factor)
   (cond ((number? x) (* x factor))
         ((line? x)   (line-scale x factor))
         ((shape? x)  (shape-scale x factor))
         (else (error "unknown type"))))
```


Dispatch on Type

- Adding new data types:
  - Must change every generic operation
  - Must keep names distinct
- Adding new methods:
  - Just create generic operations

	Data type 1	Data type 2	Data type 3	Data type 4
Operation 1	Some proc	Some proc	Some proc	Some proc
Operation 2	Some proc	Some proc	Some proc	Some proc
Operation 3	Some proc	Some proc	Some proc	Some proc
Operation 4	Some proc	Some proc	Some proc	Some proc

An Alternative View of Data: Procedures with State

- A procedure has
  - **parameters** and **body** as specified by λ expression
  - **environment** (which can hold name-value bindings!)

An Alternative View of Data: Procedures with State

- A procedure has
  - **parameters** and **body** as specified by λ expression
  - **environment** (which can hold name-value bindings!)

- Can use procedure to encapsulate (and hide) data, and provide controlled access to that data
  - Procedure application creates private environment
  - Need access to that environment
    - constructor, accessors, mutators, predicates, operations
    - mutation: changes in the private state of the procedure

Example: Pair as a Procedure with State

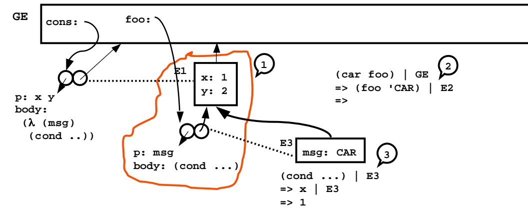
```
(define (cons x y)
  (lambda (msg)
    (cond ((eq? msg 'CAR) x)
          ((eq? msg 'CDR) y)
          ((eq? msg 'PAIR?) #t)
          (else (error "pair cannot" msg)))))


(define (car p)   (p 'CAR))
(define (cdr p)   (p 'CDR))
(define (pair? p)
  (and (procedure? p) (p 'PAIR?)))
```


Example: What is our "pair" object?

```
(define (cons x y)
  (lambda (msg)
    (cond ((eq? msg 'CAR) x)
          ((eq? msg 'CDR) y)
          ((eq? msg 'PAIR?) #t)
          (else (error "pair cannot" msg)))))
```

`(define foo (cons 1 2))` (1)

`(car foo)` (2) becomes `(foo 'CAR)` (3)



Pair Mutation as Change in State

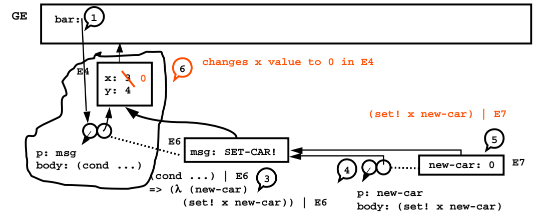
```
(define (cons x y)
  (lambda (msg)
    (cond ((eq? msg 'CAR) x)
          ((eq? msg 'CDR) y)
          ((eq? msg 'PAIR?) #t)
          ((eq? msg 'SET-CAR!)
           (lambda (new-car) (set! x new-car)))
          ((eq? msg 'SET-CDR!)
           (lambda (new-cdr) (set! y new-cdr)))
          (else (error "pair cannot" msg)))))

(define (set-car! p new-car)
  ((p 'SET-CAR!) new-car))
(define (set-cdr! p new-cdr)
  ((p 'SET-CDR!) new-cdr))
```


Example: Mutating a pair object

`(define bar (cons 3 4))` (1)

`(set-car! bar 0)`

```
(set-car! bar 0) | GE
=> ((bar 'SET-CAR!) 0) | E5
```



Message Passing Style - Refinements

- lexical scoping for private state *and* private procedures

```
(define (cons x y)
  (define (change-car new-car) (set! x new-car))
  (define (change-cdr new-cdr) (set! y new-cdr))
  (lambda (msg . args)
    (cond ((eq? msg 'CAR) x)
          ((eq? msg 'CDR) y)
          ((eq? msg 'PAIR?) #t)
          ((eq? msg 'SET-CAR!)
           (change-car (first args)))
          ((eq? msg 'SET-CDR!)
           (change-cdr (first args)))
          (else (error "pair cannot" msg)))))

(define (car p)            (p 'CAR))
(define (set-car! p val)   (p 'SET-CAR! val))
```


Variable number of arguments

A scheme mechanism to be aware of:

- Desire:
  `(add 1 2)`
  `(add 1 2 3 4)`

- How do this?

```
(define (add x y . rest)  ...)
(add 1 2)         =>  x bound to 1
                      y bound to 2
                      rest bound to '()
(add 1)           => error; requires 2 or more args
(add 1 2 3)       => rest bound to (3)
(add 1 2 3 4 5)   => rest bound to (3 4 5)
```

Programming Styles – Procedural vs. Object-Oriented

- Procedural programming:
  - Organize system around procedures that operate on data

```
(do-something <data> <arg> ...)
(do-another-thing <data>)
```

- Object-oriented programming:
  - Organize system around objects that receive messages

```
(<object> 'do-something <arg>)
(<object> 'do-another-thing)
```

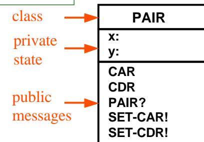
  - An object encapsulates data and operations

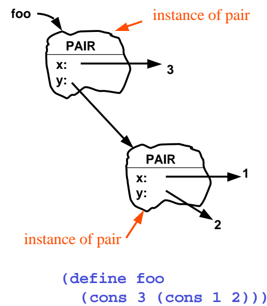
Object-Oriented Programming Terminology

- **Class**:
  - specifies the common behavior of entities
  - in Scheme, a **<type>** procedure that makes instances of this type when called with the initial values of the state variables of the instance
- **Instance**:
  - A particular object or entity of a given class
  - in Scheme, we implement an instance as the message-handling procedure made by the maker procedure
  - (Slightly more complex in Project 4.)

Class Diagram / Instance Diagram

Abstract View





User's View

```
(define (cons x y)
  (λ (msg) ...))
```

```
(define foo
  (cons 3 (cons 1 2)))
```

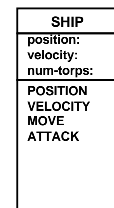

Using classes & instances to design a system

- Suppose we want to build a "space wars" simulator
- We can start by thinking about what kinds of objects we want (what classes, their state information, and their interfaces)
  - ships
  - space-stations
  - other objects
- We can then extend to thinking about what particular instances of objects are useful
  - Millenium Falcon
  - Enterprise
  - Babylon3

Space-Ship Class of Objects

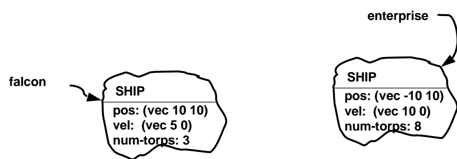
```
(define (ship position velocity num-torps)
 (define (move)
   (set! position (add-vect position velocity)))
 (define (fire-torp)
   (cond ((> num-torps 0) ...)
         (else 'FAIL)))
 (lambda (msg)
   (cond ((eq? msg 'POSITION) position)
         ((eq? msg 'VELOCITY) velocity)
         ((eq? msg 'MOVE) (move))
         ((eq? msg 'ATTACK) (fire-torp))
         (else (error "ship can't" msg)))))
```


Space-Ship Class



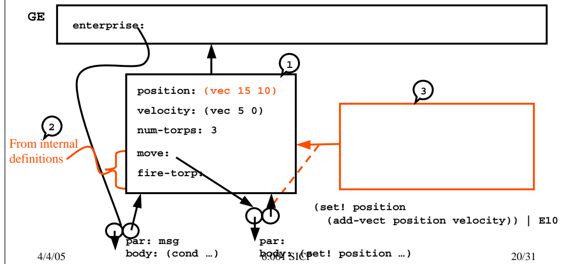
Example – Instance Diagram

```
(define enterprise
  (ship (make-vect 10 10) (make-vect 5 0) 3))
(define falcon
  (ship (make-vect -10 10) (make-vect 10 0) 8))
```



Example – Environment Diagram

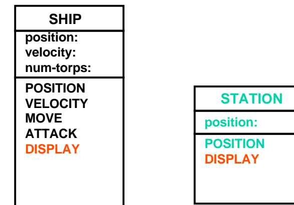
```
(define enterprise
  (ship (make-vect 10 10) (make-vect 5 0) 3))
(enterprise 'MOVE) ==> DONE
(enterprise 'POSITION) ==> (vect 15 10)
```



Some Extensions to our World

- Add more classes to our world
  - a SPACE-STATION class
  - a TORPEDO class
- Add display handler to our system
  - Draws objects on a screen
  - Can be implemented as a procedure (e.g. **draw**)
    - not everything has to be an object!
  - Add 'DISPLAY message to classes so objects will display themselves upon request (by calling draw procedure)

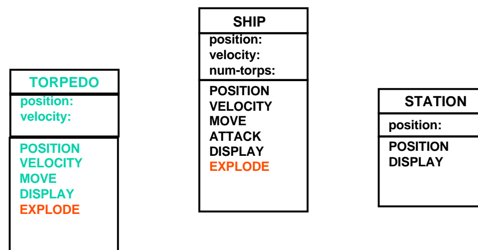
Add Space-Station Class



Station Implementation

```
(define (station position)
  (lambda (msg)
    (cond ((eq? msg 'POSITION) position)
          ((eq? msg 'DISPLAY) (draw ...))
          (else (error "station can't" msg)))))
```


Add Torpedo Class



Torpedo Implementation

```
(define (torpedo position velocity)
  (define (explode torp)
    (display "torpedo goes off!")
    (remove-from-universe torp))
  (define (move)
    (set! position ...))
  (lambda (msg . args)
    (cond ((eq? msg 'POSITION) position)
          ((eq? msg 'VELOCITY) velocity)
          ((eq? msg 'MOVE) (move))
          ((eq? msg 'EXPLODE) (explode (car args)))
          ((eq? msg 'DISPLAY) (draw ...))
          (else (error "No method" msg)))))
```


Application: Running a Simulation

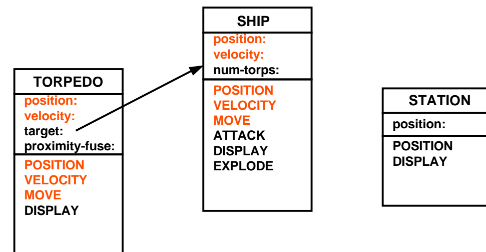
```
;; Build some things
(define babylon3 (station (make-vect 0 0)))
(define enterprise
  (ship (make-vect 10 10) (make-vect 5 0) 3))
(define falcon
  (ship (make-vect -10 10) (make-vect 10 0) 8))

;; Run a simulation
(define *the-universe* (list babylon3 enterprise falcon))
(init-clock *the-universe*)
(run-clock 100)
```

... and magical things happen on a display near you ...

Elements of Object-Oriented Programming

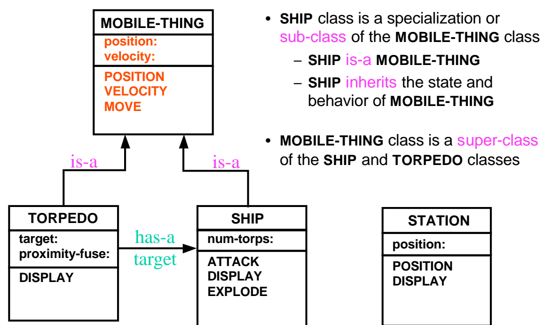
- **Object**
  - "Smart" data structure
    - Set of state variables
    - Set of methods for manipulating state variables
- **Class**:
  - Specifies the common structure and behavior of entities
- **Instance**:
  - A particular object or entity of a given class

Space War Class Diagram



Ships and torpedoes have some behavior that is the **same** – is there are way to capture this commonality?

Space War Class Diagram with Inheritance



- **SHIP** class is a specialization or sub-class of the **MOBILE-THING** class
  - **SHIP** is-a **MOBILE-THING**
  - **SHIP** inherits the state and behavior of **MOBILE-THING**
- **MOBILE-THING** class is a super-class of the **SHIP** and **TORPEDO** classes

Elements of OOP

- **Object**
  - "Smart" data structure
    - Set of state variables
    - Set of methods for manipulating state variables
- **Class**:
  - Specifies the common structure and behavior of instances
  - Inheritance to share structure and behaviors between classes
- **Instance**:
  - A particular object or entity of a given class
- **Next time: a full-bodied object-oriented system implementation**
  - **In particular, how to incorporate inheritance**

Re-Interpreting Conventional Programming as OOP

- *Smalltalk,* 1972:
  - The expression “a+b” means “send a the message + and argument b”
- Types of problems for which OOP seems particularly natural
  - Simulation (*Simula,* 1962-7)
  - GUI: Windowing systems such as X, MacOS, Windows
  - Web state (e.g., Shopping Cart)
  - Business Process Models