CS339: Abstractions and Paradigms for Programming

Imperative Programming

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Autumn 2024

An objective world…

- The world consists of independent **objects**, whose behaviour *changes* over time.
- The changing behaviour can be captured using a snapshot of the **state** of individual objects.
- The objects interact with each other and influence each other's states.
- In programming terms, the state of an object is modelled using **local state variables**.
- We next need to see how could we model such *time-varying states*.

A bank account

- **Classwork:**
  - Write a function to 'withdraw' a given amount if an account has enough balance.
  - Another function should simulate the following over an account:
  - Initial balance: 100
  - Amounts to withdraw: 20, 90, 30

Attempt 1

```
(define (withdraw balance amount)
  (if (>= balance amount)
      (- balance amount)
      (error "Insufficient balance")))

(define (account-ops)
  (withdraw (withdraw (withdraw 100 20) 90) 30))

(account-ops)
```

- Output: “Insufficient balance”

Attempt 2

```
(define (withdraw balance amount)
  (if (>= balance amount)
      (- balance amount)
      "Insufficient balance"))

(define (account-ops init-bal amounts)
  (if (null? amounts)
      init-bal
      (let ((bal (withdraw init-bal (car amounts))))
        (if (eq? bal "Insufficient balance")
            (account-ops init-bal (cdr amounts))
            (account-ops bal (cdr amounts))))))

(account-ops 100 '(20 90 30))
```

Problem: We need to maintain the balance of each account explicitly while writing our operations.

- Output: 50
- What if we had two accounts? 1000 accounts?

What we want

- An account that maintains its balance by itself.
- Users should not have to "remember" the balance of each account and supply it to the *withdraw* procedure.

- **What does it need:**
  - A way to *remember* the balance based on the history of transactions.
  - Which needs a way to *update* the balance after each transaction.
  - Which needs **mutation**!

Mutations, assignments, states

- Scheme provides a special form `set!` to update the value of a variable:
  - `set! <name> <new-value>`

Pronounced as "set bang"

- Traditionally, this is called an **assignment**.

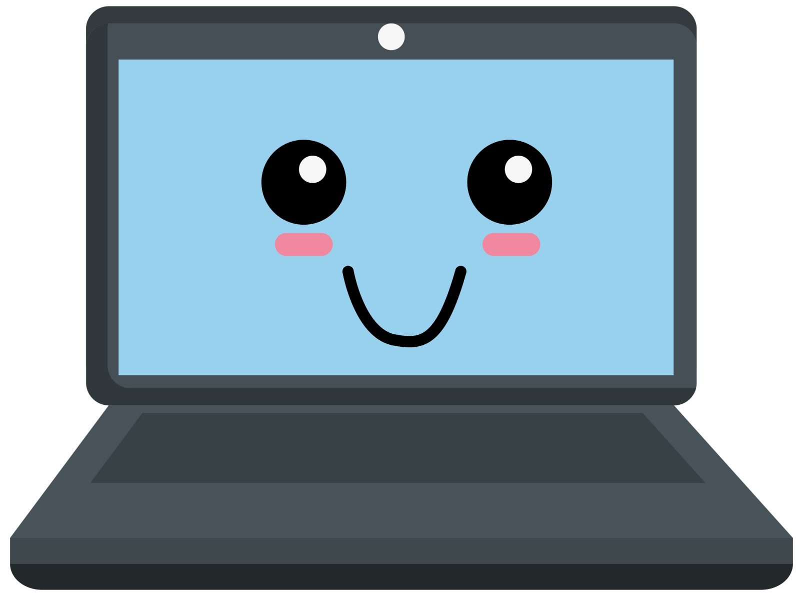
- Mutations enabled by assignments lead to the notion of a state after each assignment.

Imperative Programming

- An assignment updates the state.
- A **sequence of assignments** leads to a sequence of states.
- Hence, assignments are ***statements*** (against expressions).
- Each assignment is like a *command* to change the state.
- (Apple Dictionary) **Imperative**. giving an authoritative command.
- The practice of giving a sequence of commands to update states, in the form of assignment statements, defines the paradigm of **imperative programming**.

Account withdrawals in an imperative world

```scheme
(define balance 100)
(define (withdraw amount)
  (if (>= balance amount)
      (begin (set! balance (- balance amount))
             balance)
      "Insufficient funds"))
```



- Notice the `begin` keyword for *sequencing* multiple statements
- **PC Question:**
  - Can you recall a place where we have used ‘begin’ implicitly?
  - Answer: What about multiple defines in a procedure?

Writing “withdrawal processors”

```
(define W1 (make-withdraw 100))
(define W2 (make-withdraw 100))

> (W1 50)

50

> (W2 70)

30

> (W2 40)

“Insufficient funds”

> (W1 40)

10
```

```
(define (make-withdraw balance)
  (lambda (amount)
    (if (>= balance amount)
        (begin (set! balance (- balance amount))
               balance)
        "Insufficient funds")))
```

Multiple accounts without any hassle!

But an account can also get money in!

```
(define (make-account balance)
  (define (withdraw amount)
    (if (>= balance amount)
        (begin (set! balance (- balance amount))
               balance)
        "Insufficient funds"))
  (define (deposit amount)
    (set! balance (+ balance amount))
    balance)
  (define (dispatch m)
    (cond ((eq? m 'withdraw) withdraw)
          ((eq? m 'deposit) deposit)
          (else (error "Unknown request: MAKE-ACCOUNT"
                       m))))
  dispatch)
```

A *pakka* object-oriented account :-)

Pros of Assignments

- Ability to model the real world in terms of objects with local state
- Proper modularity: independence of objects and users
- Simpler bank account code!

Cons of Assignments

- Our nice, simple substitution model of procedure application goes away for a toss!
- Consider the following two procedures:

```
(define (make-simplified-withdraw balance)
  (lambda (amount)
    (set! balance (- balance amount))
    balance))
(define W (make-simplified-withdraw 25))
(W 20)
5
(W 10)
-5
```

Imperative

```
(define (make-decrementer balance)
  (lambda (amount)
    (- balance amount)))
(define D (make-decrementer 25))
(D 20)
5
(D 10)
15
```

Functional

Con 1: Good-bye substitution model

```
(define (make-decrementer balance)
  (lambda (amount)
    (- balance amount)))
```

```
(define (make-simplified-withdraw balance)
  (lambda (amount)
    (set! balance (- balance amount))
    balance))
```

```
((make-decrementer 25) 20)

==> ((lambda (amount) (- 25 amount)) 20)

==> (- 25 20)

==> 5
```

```
((make-simplified-withdraw 25) 20)

==> ((lambda (amount) (set! balance (- 25 amount) 25) 20)

==> (set! balance (- 25 20)) 25

==> Set balance to 5 and return 25
```

Consequence: Simple substitution may lead to unexpected results.

Con 2a: Bye-bye referential transparency

Are D1 and D2 the same?
> Arguably yes, because each could be substituted for the other.

Are W1 and W2 the same?
> They look to be, but aren't:

```
(W1 20)
5
(W1 20)
-15
(W2 20)
5
```

```
(define (make-decrementer balance)
  (lambda (amount)
    (- balance amount)))
```

```
(define D1 (make-decrementer 25))
(define D2 (make-decrementer 25))
```

```
(define (make-simplified-withdraw balance)
  (lambda (amount)
    (set! balance (- balance amount))
    balance))
```

```
(define W1 (make-withdraw 25))
(define W2 (make-withdraw 25))
```

Consequence: Can't reason about correctness by "looking" at the program.

Con 2b: Identity crisis

- Two bank accounts are different even if they have the same balance.
- A bank account remains to be the same even if its constituent data items or fields (i.e., the balance) changes.
- A rational number 2/3 is not the same if its constituent data items (either the numerator or the denominator) change.
- What's the **identity** of a bank account then?

Consequence: Extra efforts required for implementing 'equals' methods!

Con 3: Inducing order into life

- Consider this 'imperative' factorial program:

```scheme
(define (factorial n)
  (let ((product 1)
        (counter 1))
    (define (iter)
      (if (> counter n)
          product
          (begin (set! product (* counter product))
                 (set! counter (+ counter 1))
                 (iter))))
    (iter)))
```

Next class:

A substitution for substitution!

- What if we wrote or performed the assignments in opposite order:

```scheme
(set! counter (+ counter 1))
(set! product (* counter product))
```

Consequence: Difficult optimization/parallelization.