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Immutability
and Referential Transparency

Topics

- Mutation is unnecessary.
- Immutability offers referential transparency.
- Mutation complicates aliasing.
- Broader design considerations

Is immutability an obstacle or a tool?

- Programming experience in 251 and previously
- Readings about language implementation
- Efficiency in space and time
- Reliability
- Maintainability
- Ease of making/avoiding mistakes
- Clarity
- …

Mutation is unnecessary.

Patterns for accumulating results without mutation:

- Build recursively
- Create fresh copy with changes
- Explicitly thread state through (e.g., fold):
  - Function does one step, from arguments to result.
  - HOF passes result on to the next step.

Immutability offers *referential transparency*

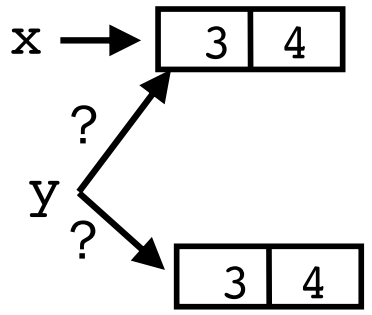
```
(define (sort-pair p)
  (if (< (car p) (cdr p))
    p
    (cons (cdr p) (car p))))

(define (sort-pair p)
  (if (< (car p) (cdr p))
    (cons (car p) (cdr p))
    (cons (cdr p) (car p))))
```

Cons cells are immutable.
Cannot tell if you copy or alias.

Consider mutation

Mutable cons cell

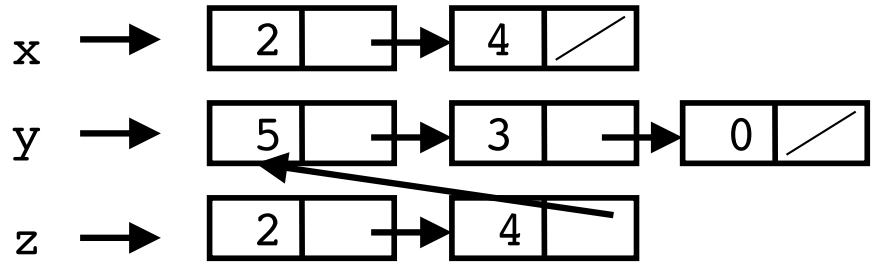
```
(define x (mcons 3 4))
(define y (sort-mpair x))

; mutate car of x to hold 5
(set-mcdr! x 5)

(define z (mcdr y))
```



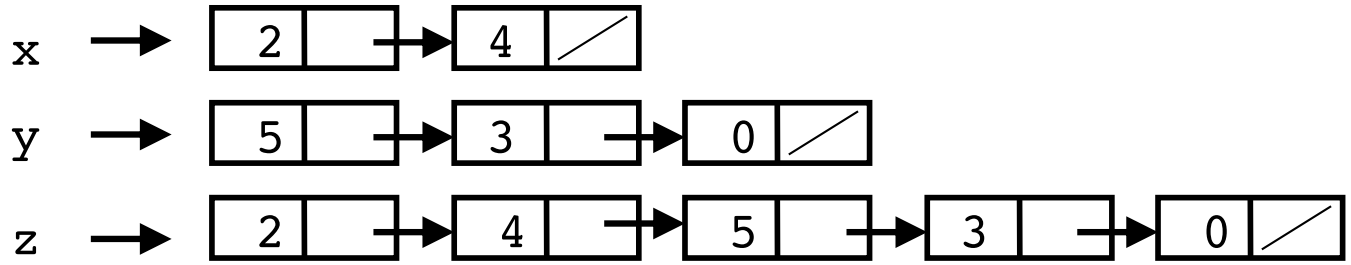
What is z?

append

```
(define (append xs ys)
  (if (null? xs)
      ys
      (cons (car xs) (append (cdr xs) ys))))
(define x (list 2 4)
(define y (list 5 3 0))
(define z (append x y))
```



or ?



Java security nightmare

```
class ProtectedResource {
   private Resource theResource = ...;
   private String[] allowedUsers = ...;
   public String[] getAllowedUsers() {
      return allowedUsers;
   }
   public String currentUser() { ... }
   public void useTheResource() {
      for (int i = 0; i < allowedUsers.length; i++) {
         if (currentUser().equals(allowedUsers[i])) {
            ... // access allowed: use it
            return;
         }
      }
      throw new IllegalAccessException();
   }
}
```

Mutant users!

The problem:

```
p.getAllowedUsers()[0] = p.currentUser();
p.useTheResource();
```

The fix:

```
public String[] getAllowedUsers() {
    … return a copy of allowedUsers …
}
```

Could this happen without mutability?

A biasing on aliasing

Immutability

- Aliasing **does not** affect correctness, just performance.
  - Other code **cannot** break your code, regardless of aliasing.
  - Changing your aliasing **cannot** break other code.
- Document what, **not** how.
- **Safe by default, optimize for performance.**

Mutability

- Aliasing **does** affect both correctness and performance.
  - Other code **can** break your code, depending on your aliasing.
  - Changing your aliasing **can** break other code.
- Document what **and** how.
- **Unsafe by default, optimize for performance and safety.**

All the more important for parallelism and concurrency…

What must we inspect to

Identify dependences between _____.

```
(define (fib n)
  (if (< n 2)
      n
      (+ (fib (- n 1)) (fib (- n 2)))))
```

Racket: immutable natural recursion

recursive calls

```
(define (fib n)
  (define (fib-tail n fibi fibi+1)
    (if (= 0 n)
        fibi
        (fib-tail (- n 1) fibi+1 (+ fibi fibi+1))))
  (fib n 0 1))
```

Racket: immutable tail recursion

Last Week

```
def fib(n):
  fib_i = 0
  fib_i_plu
  for
    f
    fi
    fi                _i_prev + fib_i_plus_1
  retur
```

Python: loop … th mutation

And maybe the whole program

loop iterations

A broader PL design theme

Design choices matter. Less can be more (reliable).

Immutability + recursion (vs. mutability + loops) are central:

- Limiting **how** programs can be expressed
- Making elements more transparent/explicit

(a.k.a., not giving programmers unmitigated access to dangerous volatile weapons)

(a.k.a., not further obscuring subtle/tricky program elements through layers of implicitness)

This style of design choice often supports:

- Simple reasoning
- Strong default guarantees
- Automated optimization opportunities

It does **not** mean limiting **what** computable functions can be implemented, just **how**.