Bugs, crawling all over

6.037 - Structure and Interpretation of Computer Programs

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Lecture 5
(define (prime? n)
  (= n (smallest-divisor n)))

(define (smallest-divisor n)
  (find-divisor n 2))

(define (find-divisor n d)
  (cond ((> (square d) n) n)
        ((divides? d n) d)
        (else (find-divisor n (+ d 1)))))

(define (divides? a b)
  (= (remainder b a) 0))
Which program is better? Why?

(define (prime? n)
  (= n (smallest-divisor n)))

(define (smallest-divisor n)
  (find-divisor n 2))

(define (find-divisor n d)
  (cond ((> (square d) n) n)
        ((divides? d n) d)
        (else (find-divisor n (+ d 1)))))

(define (divides? a b)
  (= (remainder b a) 0))

(define (prime? temp1 temp2)
  (cond ((>= temp2 temp1) #t) (= (remainder temp1 temp2) 0) #f) (else (prime? temp1 (+ temp2 1)))))
What do we mean by “better”?  

- **Correctness**  
  - Does the program compute correct results?  
  - Programming is about communicating the algorithm to the computer  
  - Is it clear what the correct result should be?
What do we mean by “better”?

- **Correctness**
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- **Clarity**
  - Can it be easily read and understood?
  - Programming is also about communicating the algorithm to people!
  - An unreadable program is a useless program
  - Does not benefit from abstraction
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- **Maintainability**
  - Can it be easily changed?
What do we mean by “better”?  

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- **Clarity**
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  - Does not benefit from abstraction  

- **Maintainability**
  - Can it be easily changed?  

- **Performance**
  - Algorithm choice: order of growth in time & space  
  - Optimization: tweaking of constant factors
Why is optimization last?

Microprocessor Transistor Counts 1971-2011 & Moore’s Law

- Curve shows transistor count doubling every two years
- Transistor count vs. Date of introduction

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(define (prime? temp1 temp2)
  (cond ((>= temp2 temp1) #t) ((= (remainder temp1 temp2) 0) #f) (else (prime? temp1 (+ temp2 1))))))
Making code more readable

```
(define (prime? temp1 temp2)
  (cond ((>= temp2 temp1) #t) ((= (remainder temp1 temp2) 0) #f) (else (prime? temp1 (+ temp2 1))))
)
```

Use indentation to show structure:

```
(define (prime? temp1 temp2)
  (cond ((>= temp2 temp1) #t)
        ((= (remainder temp1 temp2) 0) #f)
        (else (prime? temp1 (+ temp2 1))))
)
(define (prime? temp1 temp2)
  (cond ((>= temp2 temp1) #t)
        ((= (remainder temp1 temp2) 0) #f)
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Making code more readable

(define (prime? temp1 temp2)
  (cond ((>= temp2 temp1) #t)
        ((= (remainder temp1 temp2) 0) #f)
        (else (prime? temp1 (+ temp2 1)))))

Don’t ask the caller to supply extra arguments for iterative calls:

(define (prime? temp1)
  (do-it temp1 2))
(define (do-it temp1 temp2)
  (cond ((>= temp2 temp1) #t)
        ((= (remainder temp1 temp2) 0) #f)
        (else (do-it (+ temp2 1)))))))
Making code more readable

(define (prime? temp1)
  (do-it temp1 2))
(define (do-it temp1 temp2)
  (cond ((>= temp2 temp1) #t)
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(define (prime? temp1)
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(define (do-it temp1 temp2)
  (cond ((>= temp2 temp1) #t)
    ((= (remainder temp1 temp2) 0) #f)
    (else (do-it (+ temp2 1))))
)

Use block structure to hide your helper procedures:

(define (prime? temp1)
  (define (do-it temp2)
    (cond ((>= temp2 temp1) #t)
      ((= (remainder temp1 temp2) 0) #f)
      (else (do-it (+ temp2 1))))
  (do-it 2))
(define (prime? temp1)
  (define (do-it temp2)
    (cond ((>= temp2 temp1) #t)
          ((= (remainder temp1 temp2) 0) #f)
          (else (do-it (+ temp2 1))))
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  (define (do-it temp2)
    (cond ((>= temp2 temp1) #t)
      ((= (remainder temp1 temp2) 0) #f)
      (else (do-it (+ temp2 1))))
  (do-it 2))

Choose good names for procedures and variables:

(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d n) #t)
      ((= (remainder n d) 0) #f)
      (else (find-divisor (+ d 1))))
  (find-divisor 2))
(define (prime? n)
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Find useful common patterns:

(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d n) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1))))
    (find-divisor 2))

(define (divides? d n)
  (= (remainder n d) 0))
(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d n) #t)
      ((divides? d n) #f)
      (else (find-divisor (+ d 1)))))
  (find-divisor 2))

(define (divides? d n)
  (= (remainder n d) 0))
(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d (sqrt n)) #t)
      ((divides? d n) #f)
      (else (find-divisor (+ d 1)))))
  (find-divisor 2))

(define (divides? d n)
  (= (remainder n d) 0))

Focus on algorithm improvements (order of growth)
(cond ((>= d (sqrt n)) #t)
   ((divides? d n) #f)
   (else (find-divisor (+ d 1))))

Is square faster than sqrt?

(cond ((>= (square d) n) #t)
   ((divides? d n) #f)
   (else (find-divisor (+ d 1))))

What if we inline square and divides?

(cond ((>= (* d d) n) #t)
   ((= (remainder n d) 0) #f)
   (else (find-divisor (+ d 1))))

Micro-optimizations are generally useless.
Performance?

(is square faster than sqrt?)

(cond ((>= (square d) n) #t)
  ((divides? d n) #f)
  (else (find-divisor (+ d 1)))))
Performance?

(\(\text{cond} \ ((>= \ d \ (\text{sqrt} \ n)) \ #t)\)
\(\((\text{divides?} \ d \ n) \ #f)\)
\(\((\text{else} \ (\text{find-divisor} \ (+ \ d \ 1)))\))\)

Is \text{square} faster than \text{sqrt}?

(\(\text{cond} \ ((>= \ (\text{square} \ d) \ n) \ #t)\)
\(\((\text{divides?} \ d \ n) \ #f)\)
\(\((\text{else} \ (\text{find-divisor} \ (+ \ d \ 1)))\))\)

What if we inline \text{square} and \text{divides}?

(\(\text{cond} \ ((>= \ (* \ d \ d) \ n) \ #t)\)
\(\((= \ (\text{remainder} \ n \ d) \ 0) \ #f)\)
\(\((\text{else} \ (\text{find-divisor} \ (+ \ d \ 1)))\))\)
Performance?

\[
\begin{align*}
\text{(cond } & (\geq d (\text{sqrt } n)) \ #t) \\
& ((\text{divides? } d n) \ #f) \\
& (\text{else } (\text{find-divisor } (+ d 1))))
\end{align*}
\]

Is \text{square} faster than \text{sqrt}?

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\end{align*}
\]

Micro-optimizations are generally useless
Indent code for readability

Find common, **easily-named** patterns in your code, and pull them out as procedures and data abstractions
  - Makes procedures shorter, able to fit more in your head

Choose good, descriptive names for procedures and variables

**Clarity first**, then performance
  - If performance matters, focus on the algorithm first
  - Small optimizations are just constant factors
(define (primes-in-range min max)
  (cond ((> min max) '())
        ((prime? min)
         (cons min
             (primes-in-range (+ 1 min) max)))
        (else (primes-in-range (+ 1 min) max)))))
(define (primes-in-range min max)
  (cond ((> min max) '())
       ((prime? min)
        (cons min
         (primes-in-range (+ 1 min) max)))
       (else (primes-in-range (+ 1 min) max)))))
Finding prime numbers in a range

(define (primes-in-range min max)
  (let ((other-primes (primes-in-range (+ 1 min) max)))
    (cond ((> min max) '())
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(primes-in-range 0 10) ; expect (2 3 5 7)
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(primes-in-range 0 10) ; expect (2 3 5 7)
........
We all write perfect code
Dealing with bugs in your code

- We all write perfect code
- Clearly never any bugs in it
Dealing with bugs in your code

- We all write perfect code
- Clearly never any bugs in it
- But other people’s code has bugs in it
Dealing with bugs in other people’s code

What do you do when you find a bug in a program?
Dealing with bugs in other people’s code

- What do you do when you find a bug in a program?
- Write a bug report
Dealing with bugs in other people’s code

- What do you do when you find a bug in a program?
- **Write a bug report**
- Anyone can do this
What do you do when you find a bug in a program?

- Write a bug report
- Anyone can do this
- A lot of people do it *badly*
To: Alyssa P. Hacker
From: Ben Bitdiddle

Your prime-finding program doesn’t work.

Please advise.

- Ben
Questions to ask

- What did you do to cause the bug?
Questions to ask

- What did you do to cause the bug?
- Is it repeatable?
Questions to ask

- What did you do to cause the bug?
- Is it repeatable?
- What did you expect it to do?
Questions to ask

- What did you do to cause the bug?
- Is it repeatable?
- What did you expect it to do?
- What did it actually do?
Precise instructions are important
What did you do?

- Precise instructions are important
- *Simple* precise instructions are even better
What did you do?

- Precise instructions are important
- *Simple* precise instructions are even better
- *Repeatability* is key
What were you expecting?

- State and re-check your assumptions
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- Your belief of the right answer may differ from the specification of the author’s
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- State and re-check your assumptions
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; Dividing by zero is always an error
(/ 5 0)
State and re-check your assumptions

Your belief of the right answer may differ from the specification of the author’s

; Dividing by zero is always an error
(/ 5 0) ; error
What were you expecting?

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; Dividing by zero is always an error
(/ 5 0) ; error
(/ 5 0.)
What were you expecting?

- State and re-check your assumptions
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```plaintext
; Dividing by zero is always an error
(/ 5 0) ; error
(/ 5 0.) ; +inf.0
```
What were you expecting?

- State and re-check your assumptions
- Your belief of the right answer may differ from the specification of the author’s
  
  ; Dividing by zero is always an error
  (/ 5 0) ; error
  (/ 5 0.) ; +inf.0

- Sometimes the bug is in the user
What were you expecting?

- State and re-check your assumptions
- Your belief of the right answer may differ from the specification of the author’s
  
  ; Dividing by zero is always an error
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- Sometimes the bug is in the user
- Read the documentation
What were you expecting?

- State and re-check your assumptions
- Your belief of the right answer may differ from the specification of the author’s
  
  ; Dividing by zero is always an error
  
  (/ 5 0) ; error
  
  (/ 5 0.) ; +inf.0

- Sometimes the bug is in the user
- Read the documentation
- Leave open the possibility of PEBKAC
What happened?

"It didn't work"
What happened?

“It didn’t work”
The many flavors of failure

- “Nothing happens”
The many flavors of failure

- “Nothing happens”
- ... or is it just very slow?
The many flavors of failure

- “Nothing happens”
- . . . or is it just very slow?
- . . . does it pinwheel?
The many flavors of failure

- “Nothing happens”
- ... or is it just very slow?
- ... does it pinwheel?
- ... does it consume all of your CPU?

Mikes Phillips (MIT)
The many flavors of failure

- “Nothing happens”
- . . . or is it just very slow?
- . . . does it pinwheel?
- . . . does it consume all of your CPU?
- . . . does it consume all of your memory?
The many flavors of failure

- “Nothing happens”
- ... or is it just very slow?
- ... does it pinwheel?
- ... does it consume all of your CPU?
- ... does it consume all of your memory?
- “The answer is not what I expect”
The many flavors of failure

- “Nothing happens”
- . . . or is it just very slow?
- . . . does it pinwheel?
- . . . does it consume all of your CPU?
- . . . does it consume all of your memory?
- “The answer is not what I expect”
- . . . what is the significant way in which it differs from your expectations?
The many flavors of failure

- “Nothing happens”
- . . . or is it just very slow?
- . . . does it pinwheel?
- . . . does it consume all of your CPU?
- . . . does it consume all of your memory?
- “The answer is not what I expect”
- . . . what is the significant way in which it differs from your expectations?
- “It gives an error message”
The many flavors of failure

- “Nothing happens”
- ... or is it just very slow?
- ... does it pinwheel?
- ... does it consume all of your CPU?
- ... does it consume all of your memory?
- “The answer is not what I expect”
- ... what is the significant way in which it differs from your expectations?
- “It gives an error message”
- ... and what does that message say?
The many flavors of failure

- “Nothing happens”
- ... or is it just very slow?
- ... does it pinwheel?
- ... does it consume all of your CPU?
- ... does it consume all of your memory?
- “The answer is not what I expect”
- ... what is the significant way in which it differs from your expectations?
- “It gives an error message”
- ... and what does that message say?
- ... and is there anything in the error log?
To: Alyssa P. Hacker
From: Ben Bitdiddle

primes-in-range appears to never halt. I ran:

(primes-in-range 0 10)

...and it just kept going, never outputting anything; I’d expect it to return (1 2 3 5 7). I waited for 10 minutes, but it appeared to just make my laptop hot.

- Ben
As the author, do we agree that \((\text{primes-in-range 0 10})\) should halt?
Can we replicate the error?
(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d n) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1))))
  (find-divisor 2))

(let ((other-primes (primes-in-range 0 10)))
  (cond (> min other-primes
         ((prime? (min other-primes)))))

Language: racket; memory limit: 128 MB.
> (primes-in-range 0 10)
Replicate the error

- Can we replicate the error?
Can we replicate the error?
We get a different outcome!
Can we replicate the error?

We get a different outcome!

Either this is a **different** cause, or the **same** cause with a different symptom
Can we replicate the error?

We get a different outcome!

Either this is a different cause, or the same cause with a different symptom

Always re-check you actually fixed the relevant bug at the end
Is this the simplest error case?

;; Out of memory; test from user
(primes-in-range 0 10)
Is this the simplest error case?

--; Out of memory; test from user
(primes-in-range 0 10)

--; Ditto; so 0 not at fault
(primes-in-range 9 10)
Is this the simplest error case?

;; Out of memory; test from user
(primes-in-range 0 10)

;; Ditto; so 0 not at fault
(primes-in-range 9 10)

;; Simpler upper bound
(primes-in-range 0 1)
Use abstraction barriers to your advantage

- There appears to be nothing special about 0 or 10
- All calls to `primes-in-range` run out of memory
Use abstraction barriers to your advantage

- There appears to be nothing special about 0 or 10
- All calls to `primes-in-range` run out of memory
- **Divide and conquer** – verify that lower abstractions work
- Abstractions (procedural and structural) are good points to check
Check the lower abstractions

(define (primes-in-range min max)
  (let ((other-primes (primes-in-range (+ 1 min) max)))
    (cond ((> min max) '())
          ((prime? min) (cons min other-primes))
          (else other-primes)))
)

;; Check that our prime? code works!
(prime? 2)
-> #t
Check the lower abstractions

(define (primes-in-range min max)
  (let ((other-primes (primes-in-range (+ 1 min) max)))
    (cond ((> min max) '())
          ((prime? min) (cons min other-primes))
          (else other-primes)))

;; Check that our prime? code works!
(prime? 2)
(define (primes-in-range min max)
  (let ((other-primes (primes-in-range (+ 1 min) max)))
    (cond ((> min max) '())
          ((prime? min) (cons min other-primes))
          (else other-primes)))))

;; Check that our prime? code works!
(prime? 2) ; -> #t
(define (primes-in-range min max)
  (let ((other-primes (primes-in-range (+ 1 min) max)))
    (cond ((> min max) '())
          ((prime? min) (cons min other-primes))
          (else other-primes)))))
(define (primes-in-range min max)
  (let ((other-primes (primes-in-range (+ 1 min) max)))
    (cond ((> min max) '())
          ((prime? min) (cons min other-primes))
          (else other-primes))))

(primes-in-range 0 10) ;; expect (2 3 5 7)

;; => (0 1 2 3 4 5 7 9)
(define (primes-in-range min max)
  (if (> min max)
      ()
      (let ((other-primes (primes-in-range (+ 1 min))))
        (if (prime? min)
            (cons min other-primes)
            other-primes)))))
(define (primes-in-range min max)
  (if (> min max)
      '()
      (let ((other-primes (primes-in-range (+ 1 min))))
        (if (prime? min)
            (cons min other-primes)
            other-primes)))))

(primes-in-range 0 10) ;; expect (2 3 5 7)
(define (primes-in-range min max)
  (if (> min max)
      ()
      (let ((other-primes (primes-in-range (+ 1 min))))
        (if (prime? min)
            (cons min other-primes)
            other-primes))))

(primes-in-range 0 10) ;; expect (2 3 5 7)
; => (0 1 2 3 4 5 7 9)
(define (primes-in-range min max)
  (if (> min max)
      ()
      (let ((other-primes (primes-in-range (+ 1 min))))
        (if (prime? min)
            (cons min other-primes)
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(primes-in-range 0 10) ;; expect (2 3 5 7)
; => (0 1 2 3 4 5 7 9)
(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d (sqrt n)) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1))))
  (find-divisor 2))

- Only works on $n \geq 2$
(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d (sqrt n)) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1))))
  (find-divisor 2))

- Only works on \( n \geq 2 \)
- Everything has hidden assumptions
(define (prime? n)
  (define (find-divisor d)
    (cond ((>= d (sqrt n)) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1)))))
  (find-divisor 2))

- Only works on $n \geq 2$
- Everything has hidden assumptions
- Document them!
Documenting code

- Documentation improves **readability**, allows for **maintenance**, and supports **reuse**.
- Describe input and output
- Any assumptions about inputs or internal state
- Interesting decisions or algorithms
(define (prime? n)
  ; Tests if n is prime (divisible only by 1 and ; itself)
  ; n must be >= 2
  ; Test each divisor from 2 to sqrt(n),
  ; since if a divisor > sqrt(n) exists,
  ; there must be another divisor < sqrt(n)
  (define (find-divisor d)
    (cond ((>= d (sqrt n)) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1))))
    (find-divisor 2))

(define (divides? d n)
  ; Tests if d is a factor of n (i.e. n/d is an integer)
  ; d cannot be 0
  (= (remainder n d) 0))
Not all comments are good

Horrid comment:

```
(define k 2) ;; set k to 2
```

Better comment:

```
(define k 2) ;; 2 is the smallest prime
```

Better yet, obviate the need for the comment:

```
(define smallest-prime 2)
```
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Better yet, obviate the need for the comment:

```
(define smallest-prime 2)
```
The how and why of comments

- Comments should explain “how” or “why”
- “What” is almost never useful
Use assertions to check assumptions and provide good errors:

```
(define (prime? n)
  ; Tests if n is prime (divisible only by 1 and itself)
  ; n must be >= 2
  (find-divisor 2))
```
Use assertions to check assumptions and provide good errors:

(define (prime? n)
  ; Tests if n is prime (divisible only by 1 and ; itself)
  (if (< n 2)
      (error "prime? requires n >= 2")
      (find-divisor 2)))
Or, better, cover all of your bases:

(define (prime? n)
  ; Tests if n is prime (divisible only by 1 and
  ; itself)
  ; n must be >= 2
  (find-divisor 2))
Or, better, cover all of your bases:

(define (prime? n)
  ; Tests if n is prime (divisible only by 1 and itself)
  (if (< n 2)
    #f
    (find-divisor 2)))
Make no assumptions?

All of your bases?

(prime? "5")
Make no assumptions?

All of your bases?

(prime? "5")
(if (<= "5" 1) #f (find-divisor 2))
Make no assumptions?

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(<= "5" 1)

Include input/output types in a comment
Make no assumptions?

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(<= "5" 1)
<=: expected argument of type <real number>;
given "5"
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All of your bases?

(prime? "5")
(if (<= "5" 1) #f (find-divisor 2))
(<= "5" 1)
<=: expected argument of type <real number>; given "5"

Include input/output types in a comment
All better!

(primes-in-range 0 10) ; (expect 2 3 5 7)
All better!

(primes-in-range 0 10) ; (expect 2 3 5 7)
(2 3 4 5 7 9)
All better!

(primes-in-range 0 10) ; (expect 2 3 5 7)
2 3 4 5 7 9

(prime? 9)
All better!

(primes-in-range 0 10) ; (expect 2 3 5 7)
(2 3 4 5 7 9)

(prime? 9) ; => #t
How do you know what works?...

- Assume you get a *good* bug report
How do you know what works?...

- Assume you get a *good* bug report
- With simple, precise instructions that allow you to repeat it
How do you know what works?...

- Assume you get a *good* bug report
- With simple, precise instructions that allow you to repeat it
- Would be good if we never had this bug again...
Assume you get a *good* bug report
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Would be good if we never had this bug again...
Hey, computers are good at executing simple, precise instructions
How do you know what works?...

- Assume you get a *good* bug report
- With simple, precise instructions that allow you to repeat it
- Would be good if we never had this bug again...
- Hey, computers are good at executing simple, precise instructions
- **Write a test case** for the bug
When should you write tests?
When to write tests

- When should you write tests?
  - **ALL OF THE TIME.**

---

Mike Phillips (MIT)  
Bugs, crawling all over  
Lecture 5  
43 / 58
When should you write tests?

ALL OF THE TIME.

Mostly after a bug is found
When to write tests

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- You can also write tests *before* a feature is added – “test-first methodology”

Mike Phillips (MIT)
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When should you write tests?

ALL OF THE TIME.

- Mostly after a bug is found
- You can also write tests before a feature is added – “test-first methodology”
- But at least a tests-sometime methodology is key
- Test each moving part before you use it elsewhere
Choosing good test cases

- How do you choose what to test?

- Start with simple cases
- Test the boundaries of your data and recursive cases
- Check a variety of kinds of input (empty list, single element, many)
How do you choose what to test?
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Choosing good test cases

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(prime? 0) ;; Test the lower limits
(prime? 1)
(prime? 2)
(prime? 3)
(prime? 7) ;; Simple should-be-true test
(prime? 10) ;; Simple should-be-false test
(prime? 9) ;; Square numbers should be false
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(define (prime? n)
  ;; Tests if n is prime (divisible only by 1 and
  ;; itself)

  ;; Test each divisor from 2 to sqrt(n),
  ;; since if a divisor > sqrt(n) exists,
  ;; there must be another divisor < sqrt(n)
  (define (find-divisor d)
    (cond ((>= d (sqrt n)) #t)
          ((divides? d n) #f)
          (else (find-divisor (+ d 1)))))

  (if (< n 2)
      #f
      (find-divisor 2)))
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“What will this change break?”

“Did I actually fix the bug?”
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- You can keep maybe about 50k LOC in your head at once
“What will this change break?”

- “Did I actually fix the bug?”
- Having tests means not needing to know all of the code
- Small changes can have far-reaching impacts
- You can keep maybe about 50k LOC in your head at once
- Tests keep the proper functionality on disk, not in your head
“When did I break this functionality?”

- Tests written now are like debugging in the past
“When did I break this functionality?”

- Tests written now are like debugging in the past
- Run your test against old versions of your code
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When did I break this functionality?

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- If it ever worked, you’ll find what change broke it
- *Bisection* in time is awesome
- (but only as awesome as your ability to use your version control)
“Why did I do it that way?”

- Store your code in “version control”
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- Version control lets you group a set of changes into a chunk
- And then write a message about the how and why of the change
- Commit messages are like comments – the intended audience is you in the future
How to write tests

- Languages have test frameworks
  - JUnit (Java), PyUnit (Python), Test::Unit (Ruby), Test::More (Perl)
How to write tests

- Languages have test frameworks
- JUnit (Java), PyUnit (Python), Test::Unit (Ruby), Test::More (Perl)
- Racket has RackUnit
(require rackunit)
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(check-false (prime? 0) "0 is composite")
(check-false (prime? 1) "1 is composite")
(check-true (prime? 2) "2 is the smallest prime")
(check-true (prime? 3) "3 is also prime")
(require rackunit)

(check-false (prime? 0) "0 is composite")
(check-false (prime? 1) "1 is composite")
(check-true  (prime? 2) "2 is the smallest prime")
(check-true  (prime? 3) "3 is also prime")
(check-true  (prime? 7) "Larger prime")
(require rackunit)

(check-false (prime? 0) "0 is composite")
(check-false (prime? 1) "1 is composite")
(check-true (prime? 2) "2 is the smallest prime")
(check-true (prime? 3) "3 is also prime")
(check-true (prime? 7) "Larger prime")
(check-false (prime? 10) "Divisible by 2 is composite")
(require rackunit)

(check-false (prime? 0) "0 is composite")
(check-false (prime? 1) "1 is composite")
(check-true  (prime?  2) "2 is the smallest prime")
(check-true  (prime?  3) "3 is also prime")
(check-true  (prime?  7) "Larger prime")
(check-false (prime? 10) "Divisible by 2 is composite")
(check-false (prime?  9) "Square means composite")
(display ... )
Reasons why display is awesome

- Learn the name of one function, and you can debug in a new language
Reasons why display is awesome

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  (display "No fallback value found!")
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  (display "No fallback value found!"")
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  (display retval)
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- Provides written log of code decisions
- Find out which branch the code took?
  (display "No fallback value found!")
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  (display retval)
- Find if a function is called?
Reasons why display is awesome

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- Faster to implement than learning a new debugger
- Provides written log of code decisions
- Find out which branch the code took?
  (display "No fallback value found!"

Find out the return value of a function?
  (display retval)

Find if a function is called?
  (display "IaIaCthuluFtagn() called!")
Interactive debuggers

Welcome to DrRacket, version 5.0.2 [3m].
Language: Pretty Big [custom]; memory limit: 128 MB.
Interactive debuggers

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Language: Pretty Big [custom]; memory limit: 128 MB.
Go – Continue until you hit a breakpoint
Interactive debugger glossary

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Breakpoint – Function or line to stop at
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Step over – Run until we have the value of the current expression, or hit a breakpoint
Interactive debugger glossary

Go – Continue until you hit a breakpoint

Breakpoint – Function or line to stop at

Watch – Value or expression to continuously display

Step – Proceed to next expression

Step over – Run until we have the value of the current expression, or hit a breakpoint

Out – Run until we have the value of the surrounding expression, or hit a breakpoint
Interactive debugger glossary

**Go** – Continue until you hit a breakpoint

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**Watch** – Value or expression to continuously display

**Step** – Proceed to next expression

**Step over** – Run until we have the value of the current expression, or hit a breakpoint

**Out** – Run until we have the value of the surrounding expression, or hit a breakpoint

**Call stack** – Nested list of function calls that we are in; also, “backtrace.”
Heisenbugs

- Some bugs go away when you examine them
Heisenbugs

- Some bugs go away when you examine them
- Debugging statements can have side effects
Heisenbugs

- Some bugs go away when you examine them
- Debugging statements can have side effects

```
(define foo 0)
(define (new-foo) (set! foo (add1 foo)) foo)

(define sum 0)
(display
  (let loop ()
    (if (< foo 10)
      (begin
        (set! sum (+ sum (new-foo)))
        (loop))
      sum)))
```
Heisenbugs

- Some bugs go away when you examine them
- Debugging statements can have side effects

```
(define foo 0)
(define (new-foo) (set! foo (add1 foo)) foo)

(define sum 0)
(display
  (let loop ()
    (if (< foo 10)
      (begin
        (display (new-foo))(newline)
        (set! sum (+ sum (new-foo)))
        (loop))
      sum)))
```
Some error messages tell you immediately what you should be looking for
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**application**: not a procedure; expected a procedure that can be applied to arguments, given: 6; arguments were: 7 8
Common failure paradigms

- Some error messages tell you immediately what you should be looking for

  application: not a procedure; expected a procedure that can be applied to arguments, given: 6; arguments were: 7 8

  cdr: expects argument of type <pair>; given ()
Common failure paradigms

- Some error messages tell you immediately what you should be looking for

- application: not a procedure; expected a procedure that can be applied to arguments, given: 6; arguments were: 7 8

- cdr: expects argument of type <pair>; given ()

- cannot reference an identifier before its definition: parameter
Common failure paradigms

- Some error messages tell you immediately what you should be looking for
  
  **application**: not a procedure; expected a procedure that can be applied to arguments, given: 6; arguments were: 7 8

  **cdr**: expects argument of type `<pair>`; given ()

  **cannot reference an identifier before its definition**: parameter

- Learn them for your given language (ConcurrentModificationException, null pointer dereference, etc)