Bugs, crawling all over
6.037 - Structure and Interpretation of Computer Programs

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Lecture 5
Which program is better? Why?

\begin{verbatim}
(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))
\end{verbatim}
Which program is better? Why?

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    (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**
  - Does the program compute correct results?
  - Programming is about communicating the algorithm to the computer
  - Is it clear what the correct result should be?

- **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
What do we mean by “better”?

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

The graph shows the transistor count of microprocessors from 1971 to 2011, doubling every two years, as per Moore’s Law. The curve indicates an exponential increase in the number of transistors over time.

Date of introduction

Transistor count


2,300 10,000 100,000 1,000,000 2,600,000,000

8088 8086 80286 80386 80486

1802 RCA

6800 6800 6802

Pentium II

AMD K7

AMD K5-III

AMD K6

Pentium III

Pentium

AMD K6

Barton

Atom

6-core SPARC T3

16-core SPARC T3

8-core POWER7

8-core POWER7

Quad-core "brick"

I7-2600

I7-2630QM

I7 (Quad)

I7-2810QM

I7-2820QM

I7-2840QM

I7-3770K

I7-3820K

I7-3970X

I7-4700K

I7-4770K

I7-4930K

I7-5930K

I7-6950X

I7-8809G

I7-8860K

I7-8870K

I7-8890G

I7-8940K
(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) (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)
        (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))))
)

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))))
)
(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))))))
(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)))))

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

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)
Performance?

(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?

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

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

\[
(\text{cond } ((\geq (\text{square } d) n) \ #t)
\quad((\text{divides? } d n) \ #f)
\quad(\text{else } (\text{find-divisor } (+ \ d 1))))
\]
Performance?

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

Is square faster than \sqrt{ }? 

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

What if we inline square and divides? 

\[
\begin{align*}
(\text{cond } ((\geq (* d d) \ n) \ #t) \\
(= (\text{remainder } n \ d) 0) \ #f) \\
(\text{else } (\text{find-divisor } (+ d 1))))
\end{align*}
\]
Performance?

\[
\text{(cond } ((\geq d (\sqrt{n})) \text{ #t}) \\
\quad ((\text{divides? } d n) \text{ #f}) \\
\quad (\text{else } (\text{find-divisor } (+ \; d \; 1))))
\]

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

\[
\text{(cond } ((\geq (\text{square } d) n) \text{ #t}) \\
\quad ((\text{divides? } d n) \text{ #f}) \\
\quad (\text{else } (\text{find-divisor } (+ \; d \; 1))))
\]

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

\[
\text{(cond } ((\geq (* \; d \; d) n) \text{ #t}) \\
\quad ((\text{remainder } n d 0) \text{ #f}) \\
\quad (\text{else } (\text{find-divisor } (+ \; d \; 1))))
\]

Micro-optimizations are generally useless
Making code more readable

- 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)))))
Finding prime numbers in a range

```
(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)
  (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)
(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)
).
Finding prime numbers in a range

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

(primes-in-range 0 10) ; expect (2 3 5 7)
........
Dealing with bugs in your code

- 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?
What do you do when you find a bug in a program?

Write a bug report
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?
What did you do?

- Precise instructions are important
What did you do?

- Precise instructions are important
- *Simple* precise instructions are even better
Precise instructions are important

*Simple* precise instructions are even better

*Repeatability* is key
What were you expecting?

- State and re-check your assumptions
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
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)
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?

- 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.)
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

```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
  (/ 5 0) ; error
  (/ 5 0.) ; +inf.0

- 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"

Mike Phillips (MIT)  Bugs, crawling all over  Lecture 5  21 / 58
“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?
- "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?
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”
"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?
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The many flavors of failure

- “Nothing happens”
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- ... does it consume all of your CPU?
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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?
```racket
#lang racket
(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? a b)
  (= (remainder n a) 0))

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

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

The evaluation thread is no longer running, so no evaluation can take place until the next execution.

The program ran out of memory.
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
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
(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))))

;; Check that our prime? code works!
(prime? 1)
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? 1) ; -> #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))))

(primes-in-range 0 10) ;; expect (2 3 5 7)
;; => (0 1 2 3 4 5 7 9)
(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)
(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)
            other-primes)))))

(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
  (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
```
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)
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)
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))
All of your bases?

(prime? "5")
(if (<= "5" 1) #f (find-divisor 2))
(<= "5" 1)
All of your bases?

(prime? "5")
(if (<= "5" 1) #f (find-divisor 2))
(<= "5" 1)
<=: expected argument of type <real number>;
given "5"
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)
(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...
How do you know what works?...

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- 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 should you write tests?

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

- ALL OF THE TIME.
- Mostly after a bug is found
When should you write tests?

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

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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
When to write tests

- 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?

Start with simple cases
Choosing good test cases

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Choosing good test cases

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- Check a variety of kinds of input (empty list, single element, many)
Choosing good test cases

- Test the lower limits:
  - prime? 0
  - 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.
Choosing good test cases

(prime? 0) ;; Test the lower limits
(prime? 1)
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Choosing good test cases

(prime? 0) ;; Test the lower limits
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(prime? 7) ;; Simple should-be-true test
Choosing good test cases

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(prime? 3)
(prime? 7) ;; Simple should-be-true test
(prime? 10) ;; Simple should-be-false test
Choosing good test cases

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

“Did I actually fix the bug?”
What will this change break?

- Did I actually fix the bug?
- Having tests means not needing to know all of the code
“What will this change break?”

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Small changes can have far-reaching impacts
“What will this change break?”

- “Did I actually fix the bug?”
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- Small changes can have far-reaching impacts
- 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
“When did I break this functionality?”

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- If it ever worked, you’ll find what change broke it
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- *Bisection* in time is awesome
“When did I break this functionality?”

- Tests written now are like debugging in the past
- Run your test against old versions of your code
- 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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- And then write a message about the how and why of the change
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“Why did I do it that way?”

- Store your code in “version control”
- Git, Subversion, Mercurial, Bazaar, DARCS, CVS, RCS, SCCS, . . .
- 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)
(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")
(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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- Faster to implement than learning a new debugger
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  (display "No fallback value found!")
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  (display "No fallback value found!")
- Find out the return value of a function?
  (display retval)
Reasons why display is awesome

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- 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?
Reasons why display is awesome

- Learn the name of one function, and you can debug in a new language
- 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

```
(define (my-+ a b)
  (if (zero? a)
      b
      (my-+ (sub1 a) (add1 b)))))

(define (my-* a b)
  (if (zero? b)
      a
      (* a (sub1 b)))))
```

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

```
(define (my-+ a b)
  (if (zero? a)
      b
      (my-+ (sub1 a) (add1 b))))

(define (my-* a b)
  (if (zero? b)
      0
      (my-+ a (my-* a (sub1 b)))))

(my-* 3.5 2)
```

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

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

```scheme
(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
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
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)