Usability of error messages for introductory students

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Introduction to error messages

- In programming, an error is when the computer cannot understand an expression in the code
  - these errors will return an error message
- Here's an example of an error message:

```
print("Hello World";
->java.3: error: unclosed string literal
```

Importance of error messages

- Error messages are important tool for beginner programmers
  - one of the primary interactions between the system and the user
- Unhelpful error messages impose learning difficulties, especially for new programmers
- Error messages with poor usability can lead the user down the wrong path

Goals of an error message

- An error message should:
  - not add confusion
  - be easy to understand
  - help a student locate the issue
- Example:

```
Developing...
```

Analyzing error messages

- Human-computer interaction: study on interfaces between user and programs
- Much of the research presented from an HCI perspective
- We will discuss error messages in terms of usability

Outline

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Compiler errors

- When a compiler fails to compile a program, a user will receive a compiler error message
- For newer programmers, these typically occur from syntax errors
- Example (in Java):

```
int seven = (2 + 5;
error: ')' expected
```

Runtime errors

- A runtime error occurs after a program has compiled
- Usually indication of logical errors in the code
- Cannot be predicted, dependent on the values
- Example:

```
String string = "Hello World";
System.out.print(string.substring(6,12));

java.lang.StringIndexOutOfBoundsException:
String index out of range: 12
```

Statically typed

- All variables and/or objects assigned types
- Type checking done at compile time
  - this means different error messages
- Languages like Java or C++ are statically typed
- The following example would give an error at compile time in statically typed:

```
personName = "Frank"
personName = 7
```

Dynamically typed

- Values are not assigned to types
- Type checking done at runtime
- Languages in Lisp family
- The following example would give an error at runtime in dynamically typed:

```
personName = "Frank"
personName = 7
```

Outline

Overview of study

- Marceau et al. noticed students struggling with error messages in course
- Conducted study on DrRacket error messages in Spring of 2009
- Hoping to use the data to improve students' interactions with DrRacket error messages

Integrated development environments

- An integrated development environment (IDE) is a program for writing and running code
- Some IDEs come packaged with debugging tools and custom error messages

Racket programming language

- Programming language useful for teaching in introductory courses
- Member of Lisp languages
- Functional language: computation as a composition of functions and retains immutable data and avoids changing state
- dynamically typed
- Syntax example:

```
(+ 1 2)
-> 3
```

DrRacket

- An IDE for developing programs in Racket
- Geared toward introductory programmers
- DrRacket offers (mostly) user-friendly error messages and libraries to program in various levels

DrRacket interface

Study of DrRacket error messages

- Marceau et al. interested in finding which errors students struggled with
- Configured DrRacket to save a copy of each program a student tried to execute and the error messages received
- Programs taken from a once-per-week lab session

Table of results

Lab Number	#1			#2			#3			#4			#5			#6		
	%error	%bad	#bad	%error	%bad	#bad	%error	%bad	#bad	%error	%bad	#bad	%error	%bad	#bad	%error	%bad	#bad
arg. count	5%	48%	0.22	17%	27%	**0.74**	14%	17%	0.33	13%	20%	0.24	35%	21%	**0.74**	12%	31%	0.36
parens matching	28%	24%	0.58	12%	14%	0.27	17%	0%	0.00	14%	0%	0.00	13%	0%	0.00	10%	15%	0.15
runtime cond	3%	0%	0.00	3%	100%	0.49	4%	20%	0.12	6%	72%	0.40	8%	78%	**0.62**	1%	100%	0.06
runtime type	2%	100%	0.15	8%	73%	**0.91**	16%	40%	**0.93**	8%	22%	0.17	6%	44%	0.26	3%	38%	0.13
syntax cond	14%	51%	0.59	4%	50%	0.31	6%	26%	0.24	10%	28%	0.25	9%	20%	0.17	11%	11%	0.12
syntax define	16%	50%	**0.68**	14%	50%	**1.14**	6%	15%	0.14	7%	24%	0.14	2%	17%	0.03	3%	38%	0.10
syntax func call	14%	64%	**0.74**	14%	17%	0.37	12%	14%	0.26	23%	27%	0.55	4%	29%	0.12	13%	38%	0.48
syntax struct	0%	0%	0.00	8%	32%	0.43	5%	92%	**0.73**	0%	0%	0.00	1%	0%	0.00	0%	0%	0.00
unbound id.	16%	16%	0.21	13%	40%	**0.85**	16%	14%	0.32	16%	0%	0.00	20%	7%	0.14	34%	13%	0.44

KEY:
%error: Percentage of error messages during lab of the given category of errors
%bad: Percentage of error messages that were poorly responded to
#bad: Estimate of the number of errors in the category that each student responded poorly to

Results

- Students struggle with certain errors relative to skill level
- Some errors were not indicator of underlying issue
  - student struggled with these errors
  - suggests issues in error message effectiveness

Student code example

```
(define (label-near? name bias word1 word2)
  (cond
      (and (cond [(string=? name word1)
                  "Name Located"]
                 [(string=? bias word2)
                  "Bias Located"])
           (cond [(string=? name word2)
                  "Name Located"]
                 [(string=? bias word2)
                  "Bias Located"])
      "Mark")
))
```

Overview of study

- Compiler error messages often cryptic and difficult for many programmers
- Traver and his students found compiler errors messages difficult to understand
- Traver conducted study in Fall 2002 at Jaume I University to verify which errors intro students struggle with
  - course used C++ programming language

Intro to C++

- Not designed to be taught in intro course
- Imperative language: uses memory manipulation and state-changing statements to build computation
- statically-typed
- Object-oriented programming (OOP): method of programming around class hierarchy and creating objects
- Syntax example:

```
int a = 2;
a = a + 2;
cout << a;
-> 2
```

Method of study

- GNU g++ compiler was used
- Code gathered from students in lab sessions throughout semester
- Analyzed each message and wrote out the following for each message:
  - why the error occurred
  - possible alternate error message
  - why the error is unhelpful

Example of code analyzed

Offending code:

```
SavingAccount::SavingAccount(){
    float SavingAccount::getInterestRate() {
      return rate;
}
```

Error message:

```
In method 'SavingAccount::SavingAccount()':
declaration of 'float SavingAccount::getInterestRat
outside of class is not definition
```

Example continued

Alternative error message:

```
A function declaration inside a function body is
not possible. Did you forget '}' to close the
body of the previous function definition?
```

Results

- Study makes a good case for compiler error usability
- Hopes that approaches be considered to improve messages
- Helped him understand which errors students students struggled with

Outline

Recommendations

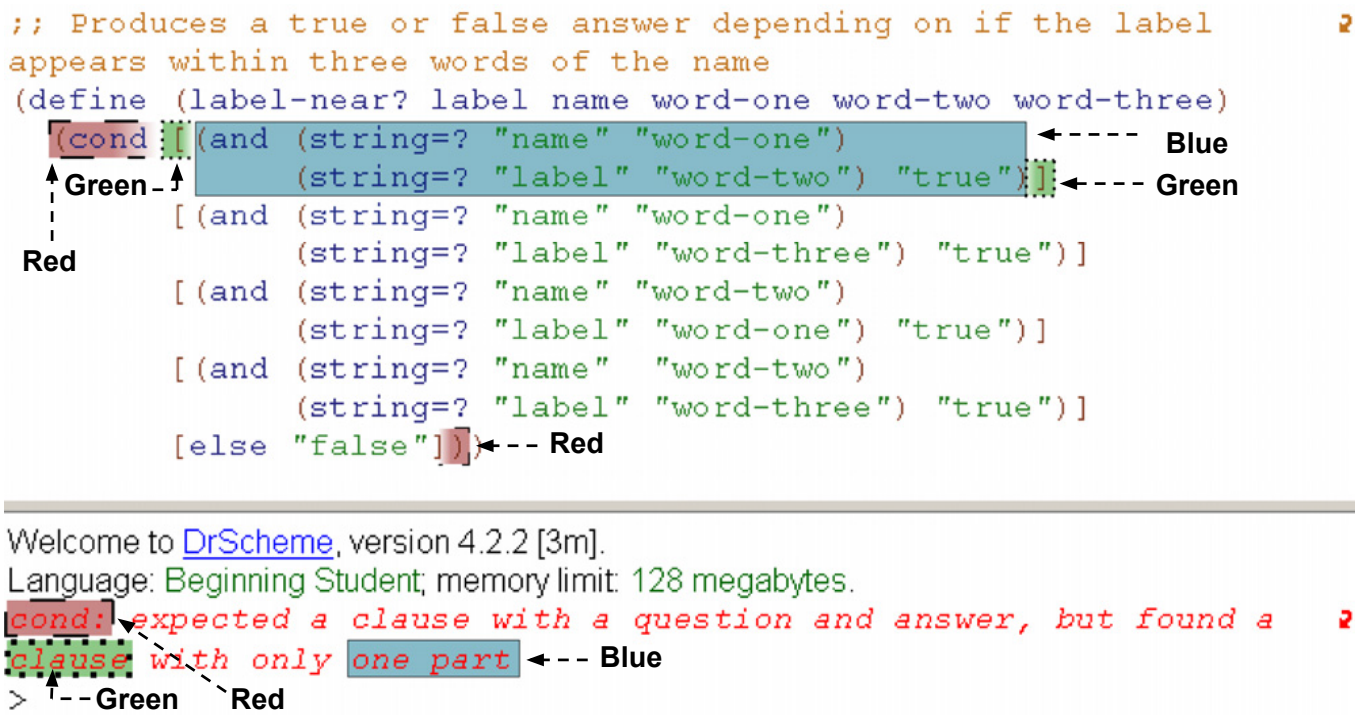
- Marceau et al. based their research on these
- Wanted to maintain two design principles:
  - error messages should not propose solutions
  - error messages should not prompt toward incorrect edits

recommendations continued

- Simplify message vocabulary
  - eg, student will understand `variable` more than `identifier`
  - these should be for lower levels in DrRacket
- Be explicit with constructor or function usage in highlighting
- Color coding references with its corresponding code

Color coded error message

Red highlights definition, green highlights clause, blue highlights definition



Future work

- Recommendations implemented in How to Design Programs (HtDP) libraries in DrRacket
- Further research needed to evaluate HtDP libraries

Intro to syntax errors

- Introductory students most likely receive many syntax errors in first few weeks of learning language
- "Syntax errors are significant barrier to student success" - Denny et al.
- Denny et al. propose to improve syntax error messages in course

Improving errors

- Course used Java, language similar to C++
- Course also used CodeWrite, online IDE
- Pulled student submissions from CodeWrite
- Match commonly erroneous code, extracted line containing error, and inserted their enhanced error

Enhanced syntax error example

It appears that there is an error in the condition below:

```
if (score < 0) || (score > 100)
```

Remember that the condition for an `if` statement must be surrounded by opening and closing parentheses:

```
if (condition)
```

This is true even if the condition consists of more than one boolean expression combined with logical operators like `&&` or `||`.

Example

Incorrect Code

```
int a = 6;
double x = 9.4;

if (x > 10) && (a == 0) {
     return true;
}
```

Correct Code

```
int a = 6;
double x = 9.4;

if ((x > 10) && (a == 0)) {
     return true;
}
```

Explanation

The condition of an if statement needs to be enclosed in parentheses. Even if the condition is made up of the combination of other conditions, the entire thing still needs to be wrapped in parentheses

Testing the enhanced syntax messages

- Students in control group (original error messages) and intervention group (enhanced error messages)
- Compared attempts of student submissions to see if it would reduce the number of non-compiling submissions overall
- Used t-tests to find results (still need to define t-test)

Results of syntax enhancement

- t-tests gave high p-values ($p > 0.05$)
  - indication of no evidence of significant difference between the groups

Future work

- Denny et al. believed several factors were cause for no significance
  - for example, students may not have paid attention to additional information
- Authors would like to apply additional research to improve their messages

Outline

Results

- Some work needs to be done with DrRacket error messages to better report the actual errors
- Compiler error messages are an issue in terms of usability
- Research is being done in attempt to improve error messages
  - Marceau et al. recommendations for error message design in IDEs
  - Denny et al. syntax error message enhancement

Future work

- HtDP libraries implemented Marceau et al. research
- Some work being done to attempt to improve compiler error messages
- Growing interest in computer science
  - more user-friendly error messages are a necessity

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Thank you for your time and attention!

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Questions?

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See my senior seminar paper for additional references.