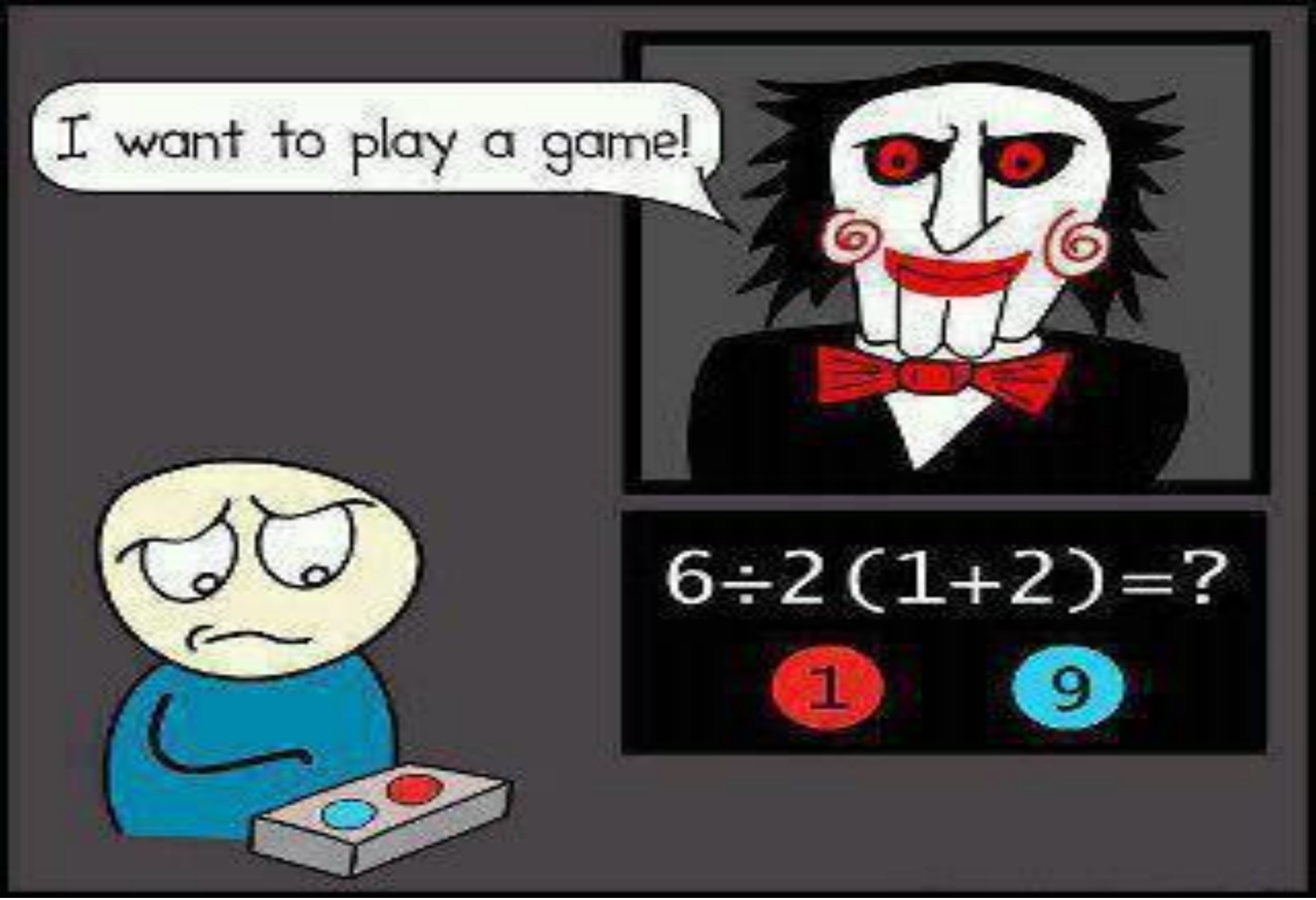
Operators and precedence (O&P) in programming language (PL) design

Najwani Razali, James Noble & Stuart Marshall
Victoria University of Wellington



http://www.hsitechnologies.com/thesolution.php

Examples of operator precedence bugs in Linux kernel

```
> -     *delay = (u16)(val & I40E_PRTDCB_GENC_PFCLDA_MASK >>
> -                    I40E_PRTDCB_GENC_PFCLDA_SHIFT);
```

Examples of operator precedence bugs in Linux kernel

```
> -     *delay = (u16)(val & I40E_PRTDCB_GENC_PFCLDA_MASK >>
> -                    I40E_PRTDCB_GENC_PFCLDA_SHIFT);
```

```
> +     *delay = (val & I40E_PRTDCB_GENC_PFCLDA_MASK) >>
> +                    I40E_PRTDCB_GENC_PFCLDA_SHIFT;
```

Wrongly used parentheses!!!!

Continue....

- if (! max77802->opmode[id] == MAX77802_OFF_PWRREQ) {

Continue....

```
-       if (! max77802->opmode[id] == MAX77802_OFF_PWRREQ) {

+       if (max77802->opmode[id] != MAX77802_OFF_PWRREQ) {
                dev_warn(&rdev->dev, "%s: is disabled, mode: 0x%x not set\n",
                        rdev->desc->name, mode);
                return 0;
```

CWE-783: Operator Precedence Logic Error

Operator Precedence Logic Error

Weakness ID: 783 *(Weakness Variant)* **Status:** Draft

Description

Description Summary

The program uses an expression in which operator precedence causes incorrect logic to be used.

Extended Description

While often just a bug, operator precedence logic errors can have serious consequences if they are used in security-critical code, such as making an authentication decision.

```
public double calculateReturnOnInvestment(double currentValue, double initialInvestment) {

  double returnROI = 0.0;

  // calculate return on investment
  returnROI = currentValue - initialInvestment / initialInvestment;

  return returnROI;
}
```

```
returnROI = (currentValue - initialInvestment) / initialInvestment;
```

```
#define FAIL 0
#define SUCCESS 1

...

int validateUser(char *username, char *password) {

  int isUser = FAIL;

  // call method to authenticate username and password
  // if authentication fails then return failure otherwise return success
  if (isUser = AuthenticateUser(username, password) == FAIL) {
    return isUser;
  }
  else {
    isUser = SUCCESS;
  }

  return isUser;
}
```

```
if ((isUser = AuthenticateUser(username, password)) == FAIL) {
```

Consequences:
-Confidentiality
- Integrity
- Availability

http://cwe.mitre.org/data/definitions/783.html

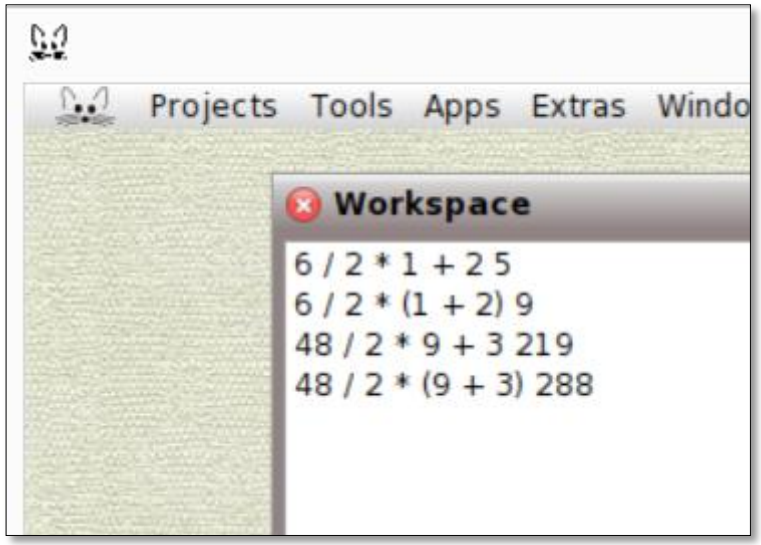
Is Knight's $440 million glitch the costliest computer bug ever?

By Brian Patrick Eha @CNNTech August 9, 2012: 10:22 AM ET

SPENCER PLATT/GETTY IMAGES

Knight Capital's computer bug cost the firm $440 million, making it one of history's most expensive software glitches.

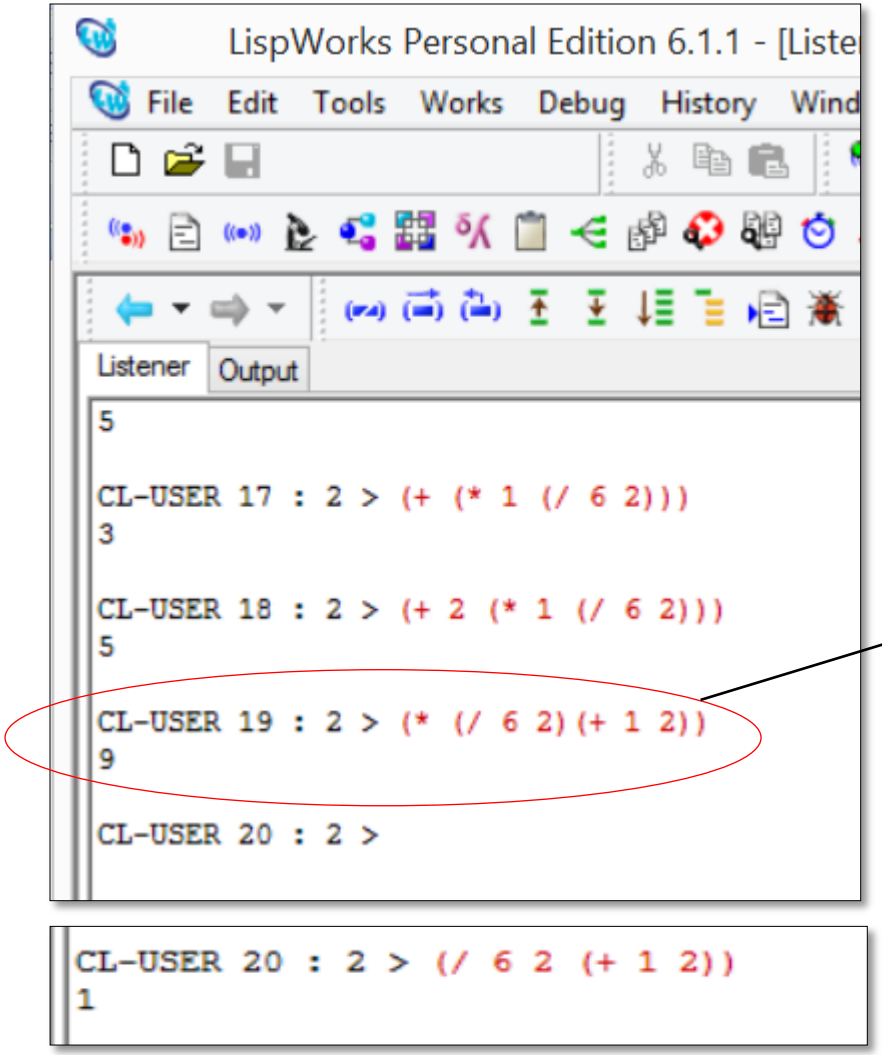
Smalltalk



Order of evaluation:

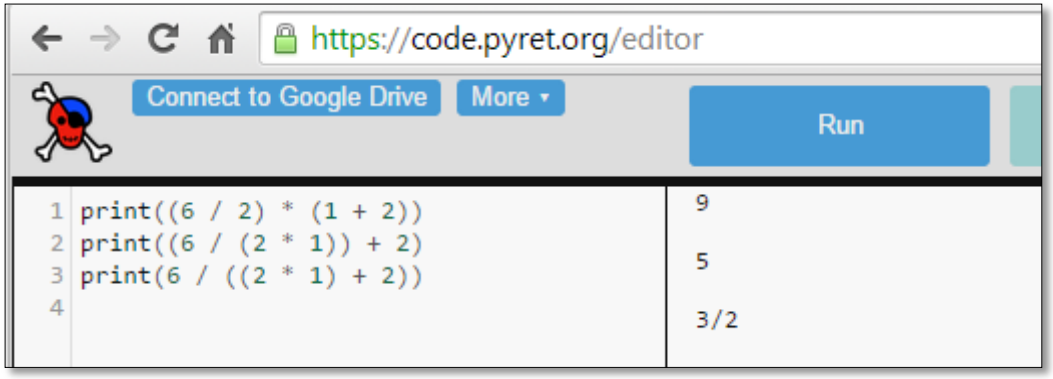
1. Parentheses
2. Unary message sends (left to right)
3. Binary message sends (left to right)
4. Keyword message sends
5. Assignments
6. Returns

LISP



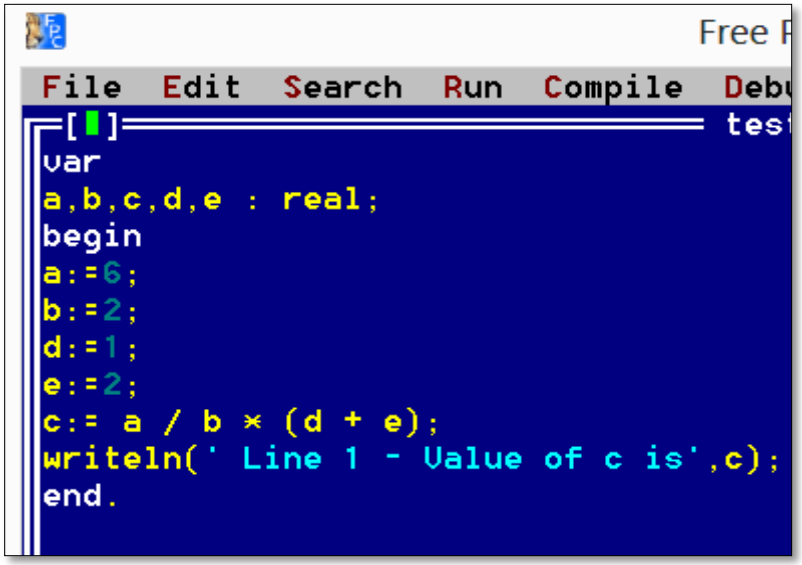
1. Required parentheses
2. Prefix expression

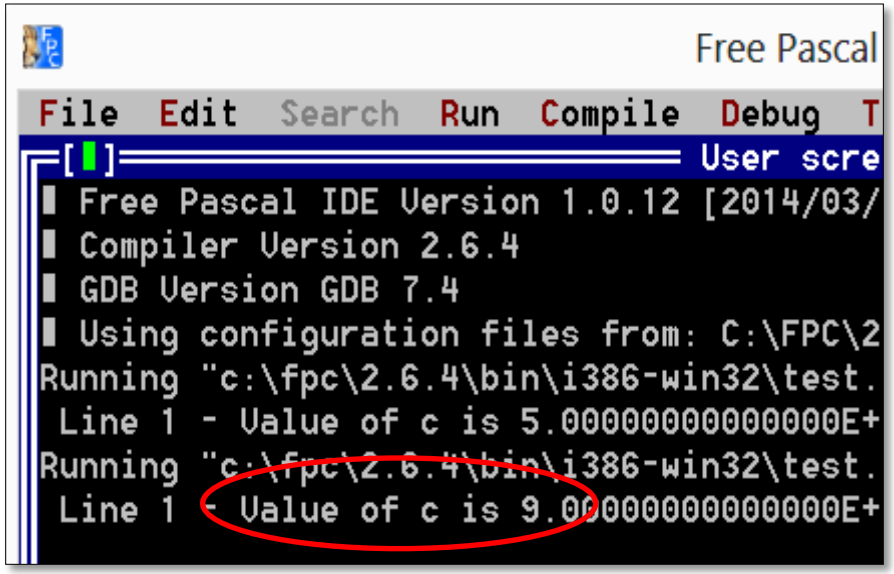
Pyret


https://code.pyret.org/editor
Connect to Google Drive
More
Run
1 print((6 / 2) * (1 + 2))
2 print((6 / (2 * 1)) + 2)
3 print(6 / ((2 * 1) + 2))
4
9
5
3/2


https://code.pyret.org/editor
Connect to Google Drive
More
Run
Stop
1
2 print(6 / 2 * 1 + 2)
3
Cannot mix binary operators of different types: `+` and `*`. Use parentheses to disambiguate.
definitions: line 7, column 6
definitions: line 7, column 6

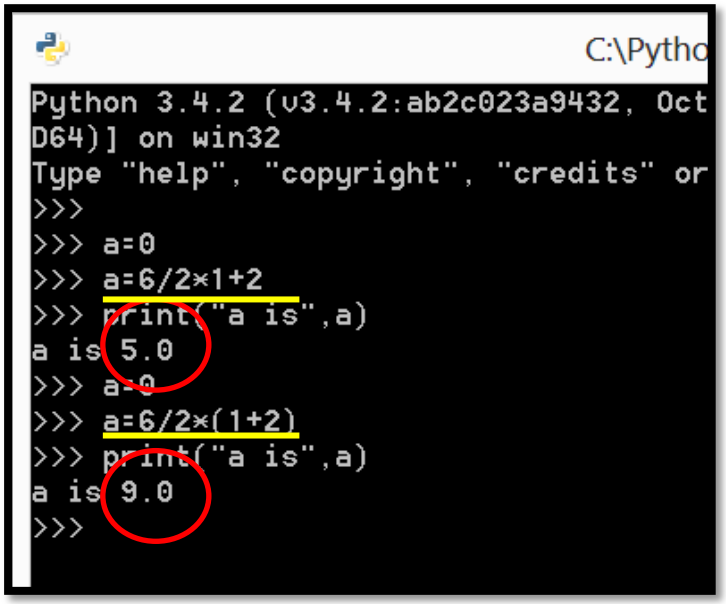
Pascal - 6 / 2 * (1 + 2)





Operator	Precedence
~, not,	Highest
*, /, div, mod, and, &	
|, !, +, -, or,	
=, <>, <, <=, >, >=, in	
or else, and then	Lowest

Python



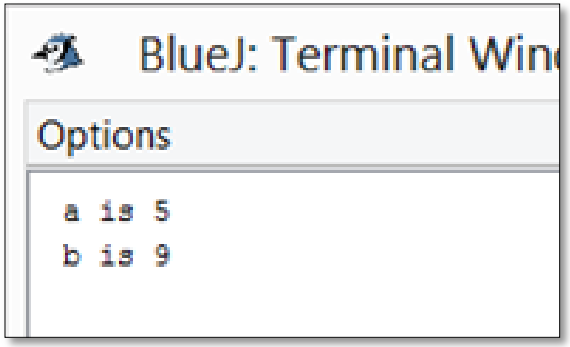
Operator	Description
`lambda`	Lambda expression
`if – else`	Conditional expression
`or`	Boolean OR
`and`	Boolean AND
`not x`	Boolean NOT
`in, not in, is, is not, <, <=, >, >=, <>, !=, ==`	Comparisons, including membership tests and identity tests
`|`	Bitwise OR
`^`	Bitwise XOR
`&`	Bitwise AND
`<<, >>`	Shifts
`+, -`	Addition and subtraction
`*, /, //, %`	Multiplication, division, remainder [8]
`+x, -x, ~x`	Positive, negative, bitwise NOT
`**`	Exponentiation [9]
`x[index], x[index:index], x(arguments...), x.attribute`	Subscription, slicing, call, attribute reference
`(expressions...), [expressions...], {key: value...}, `expressions...``	Binding or tuple display, list display, dictionary display, string conversion

JAVA

```
public class test2
{
    // instance variables - replace the exa
    public static void main(){
        int a, b = 0;

        a = 6 / 2 * 1 + 2;
        System.out.println(" a is " + a);

        b = 6 / 2 * (1 + 2);
        System.out.println(" b is " + b);
    }
}
```



Category	Operator	Associativity
Postfix	() [] . (dot operator)	Left to right
Unary	++ - - ! ~	Right to left
Multiplicative	* / %	Left to right
Additive	+ -	Left to right
Shift	>> >>> <<	Left to right
Relational	> >= < <=	Left to right
Equality	== !=	Left to right
Bitwise AND	&	Left to right
Bitwise XOR	^	Left to right
Bitwise OR	|	Left to right
Logical AND	&&	Left to right
Logical OR	||	Left to right
Conditional	?:	Right to left
Assignment	= += -= *= /= %= >>= <<= &= ^= |=	Right to left
Comma	,	Left to right

C

Compile & Execute | main.c | input.txt

```c
#include <stdio.h>
#include <string.h>

main()
{
    int a, b = 0;

    a = 6 / 2 * 1 + 2;
    printf("a is %d\n", a);

    b = 6 / 2 * (1 + 2);
    printf("b is %d\n", b);

}
```

Result

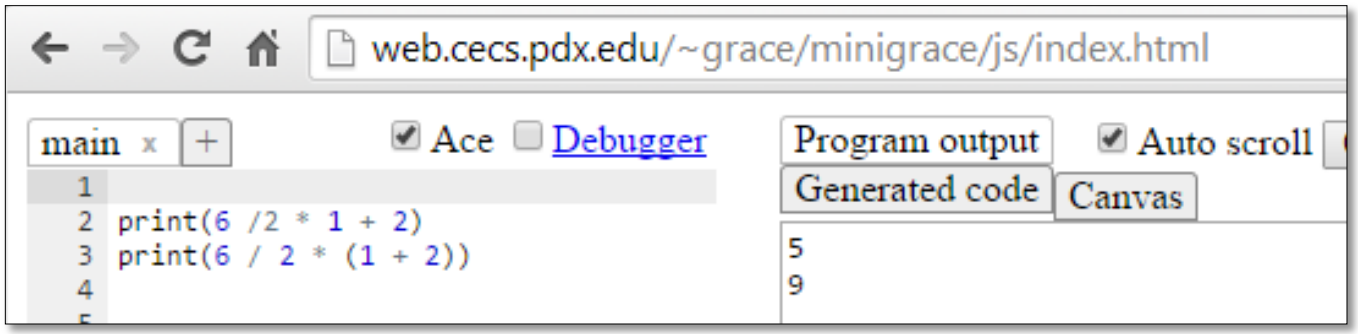
```
Compiling the source code....
$gcc main.c -o demo -lm -pth

Executing the program....
$demo

a is 5
b is 9
```

Category	Operator	Associativity
Postfix	() [] -> . ++ - -	Left to right
Unary	+ - ! ~ ++ - - (type)* & sizeof	Right to left
Multiplicative	* / %	Left to right
Additive	+ -	Left to right
Shift	<< >>	Left to right
Relational	< <= > >=	Left to right
Equality	== !=	Left to right
Bitwise AND	&	Left to right
Bitwise XOR	^	Left to right
Bitwise OR	|	Left to right
Logical AND	&&	Left to right
Logical OR	||	Left to right
Conditional	?:	Right to left
Assignment	= += -= *= /= %=>>= <<= &= ^= |=	Right to left
Comma	,	Left to right

GRACE


web.cecs.pdx.edu/~grace/minigrace/js/index.html
main
Ace
Debugger
Program output
Auto scroll
Generated code
Canvas
1
2 print(6 /2 * 1 + 2)
3 print(6 / 2 * (1 + 2))
4
5
5
9

Summary

Programming languages	Expression	Output	Rules
Pascal, Python, Java, C, C++ & Grace	6 / 2 * (1 + 2)	9	Precedence
	6 / 2 * 1 + 2	5	
	2 + 6 / 2 + 1	5	
Smalltalk	6 / 2 * (1 + 2)	9	Left-to-right
	6 / 2 * 1 + 2	5	
	2 + 6 / 2 * 1	4	
LISP	(*(/ 6 2)(+ 1 2))	9	Parenthesis & prefix
	(/ 6 2 (+ 1 2))	1	
Pyret	((6 / 2) * (1 + 2))	9	Parenthesis

Pilot study

- Participants: 1st year student in computer science, currently taking Java course from University Utara Malaysia (UUM)
- There are 29 participants
- Goals:
  - To understand and evaluate students interpretation on expression of operators and precedence

Initial findings

Question 1

Add parentheses for the expression based on their precedence in order to remove ambiguity and give the output:

1 + 2 * 3 - 4

No	Pattern of expression	answers	Total no of pattern
1	1 + (2 * 3) - 4	3	**12**
2	1 + (2 * 3) - 4 1 + 6 - 4 7 - 4	3	**13**
3	(1 + (2 * 3)) - 4	3	**3**

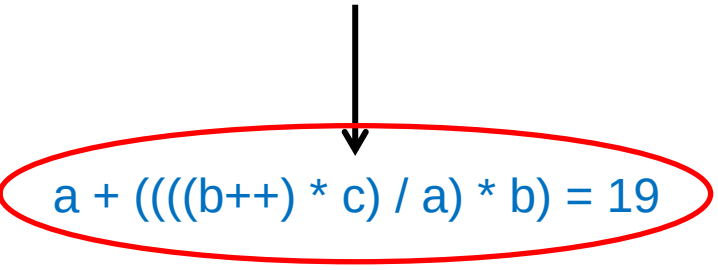
Initial findings

Question 2

Add parentheses for the expression based on their precedence in order to remove ambiguity and give the output.

```
int a = 1;
int b = 2;
int c = 3;

a + b++ * c / a * b
```



No	Pattern of expression	answers	Total no of pattern
1	a + ((b++ * c) / (a * b))	3	**6**
2	a + (b++ * c) / (a * b)	3	**4**
3	a + ((b++) * c) / (a * b)	3	**3**
4	(a + ((b++ * c) / (a * b)))	3	**1**
5	a + (((b++) * c) / (a * b))	3	**2**
6	a + (((b++) * c) / a) * b)	19	**2**
7	a + (((b++ * c) / a) * b)	19	**1**
8	((a + b++) * c) / a * b)	27	**1**
9	a + (b++) * c / a * b	19	**1**

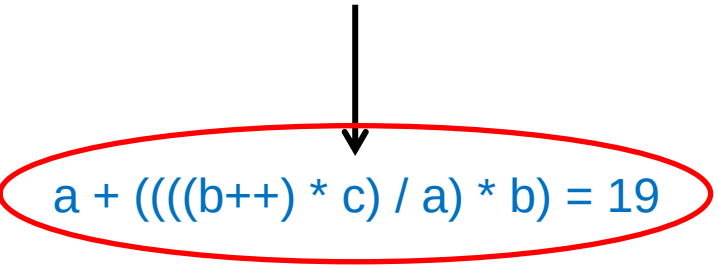
Initial findings

Question 2

Add parentheses for the expression based on their precedence in order to remove ambiguity and give the output.

```
int a = 1;
int b = 2;
int c = 3;

a + b++ * c / a * b
```



No	Pattern of expression	answers	Total no of pattern
1	a + ((b++ * c) / (a * b))	3	**6**
2	a + (b++ * c) / (a * b)	3	**4**
3	a + ((b++) * c) / (a * b)	3	**3**
4	(a + ((b++ * c) / (a * b)))	3	**1**
5	a + (((b++) * c) / (a * b))	3	**2**
6	a + (((b++) * c) / a) * b)	19	**2**
7	a + (((b++ * c) / a) * b)	19	**1**
8	((a + b++) * c) / a * b)	27	**1**
9	a + (b++) * c / a * b	19	**1**

Objectives

- To understand student conceptual understanding on O&P
- To design an empirical framework based on users interpretation on operators & precedence
- To design a tools based on the empirical framework

Goals

- Help novices (who has no background in programming) and computer science students to understand operators & precedence
- Help language designers by providing a framework as a guideline during their design stage

Thank you