Five-Minute Review

1. What is a *variable*?
2. What is a *class*? An *object*?
3. What is a *package*?
4. What is a *method*? A *constructor*?
5. What is an *object variable*?

Programming – Lecture 3

Expressions *etc.* (Chapter 3)

- Aside: Context Free Grammars
- Expressions
- Primitive types
- Aside: representing integers
- Constants, variables
- Identifiers
- Variable declarations
- Arithmetic expressions
- Operator precedence
- Assignment statements
- Booleans

Aside: Context-Free Grammars (CFGs)

Can specify **syntax** of a program (or parts of a program) as CFG

Note: “Aside” indicates that this material is not covered in the book, but still part of the class content, also relevant for exam.

For further reference, see e.g.:
https://en.wikipedia.org/wiki/Context-free_grammar

Why You Should Care About CFGs

The Java® Language Specification

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Context-Free Grammars (CFGs)

From the Java Language Standard, Sec. 2.1:

A *context-free grammar* consists of a number of *productions*.

Each production has an abstract symbol called a *nonterminal* as its *left-hand side*, and a sequence of one or more nonterminal and *terminal* symbols as its *right-hand side*. For each grammar, the terminal symbols are drawn from a specified *alphabet*.

Starting from a sentence consisting of a single distinguished nonterminal, called the *goal symbol*, a given context-free grammar specifies a *language*, namely, the set of possible sequences of terminal symbols that can result from repeatedly replacing any nonterminal in the sequence with a right-hand side of a production for which the nonterminal is the left-hand side.

https://docs.oracle.com/javase/specs/jls/se9/html/jls-2.html#jls-2.1

Context-Free Grammars (CFGs)

Formally: *CFG* defined by 4-tuple $G = (V, \Sigma, R, S)$

- V is a set of *nonterminal characters* or *variables*
- Σ, the *alphabet*, is finite set of *terminals*.
- R, the set of *(rewrite) rules* or *productions*, is relation from V to $(V \cup \Sigma)^*$, i.e., a set of ordered pairs of elements from V and $(V \cup \Sigma)^*$, respectively
- $S \in V$ is the *start variable* (or *start/goal symbol*)

Note: * is the *Kleene Star*. For any set X, X^* denotes the set of strings composed of concatenating 0 or more elements of X.

Example: $\{ 0, 1 \}^* = \{ \varepsilon, 0, 1, 00, 01, 10, 11, 000, ... \}$, where ε denotes the *empty string*

Language of CFG

For any strings u, $v \in (V \cup \Sigma)^*$,
u *directly yields* v (written $u \Rightarrow v$)
if $\exists(\alpha, \beta) \in R$ with $\alpha \in V$ and u_1, $u_2 \in (V \cup \Sigma)^*$ and
$u = u_1 \alpha u_2$ and $v = u_1 \beta u_2$.
Thus, v is a result of applying the rule (α, β) to u.

Language of grammar $G = (V, \Sigma, R, S)$ is the set
$L(G) = \{w \in \Sigma^* : S \Rightarrow^* w\}$
where $\Rightarrow^*$ is reflexive transitive closure of $\Rightarrow$

Example: Well-Formed Parentheses

Well-formed: (), (()), ()(), ()(()), …

Ill-formed: ε, (,),)(, ((), …

$G = (V, \Sigma, R, S)$ with

- Variables $V = \{ S \}$
- Alphabet $\Sigma = \{$ (,) $\}$
- Productions $R = \{ S \rightarrow SS, S \rightarrow (S), S \rightarrow () \}$

May also write R as $S \rightarrow SS \mid (S) \mid ()$

Note: one may argue that ε is also well-formed – which could also be handled with a further production $S \rightarrow \varepsilon$

$S \rightarrow SS \mid (S) \mid ()$

Claim: The string (()()) is *valid*, i.e., in $L(G)$.

Proof: consider the *derivation*

$S \Rightarrow (S) \Rightarrow (SS) \Rightarrow (()S) \Rightarrow (()())$

However, the string)(is not in $L(G)$,
since there is no derivation from S to)(

Trees in CS

Our trees grow downwards!

R: *Root*

L: *Leaf*

I: *Internal node* (i.e., not a leaf)

Typically, root is an internal node (when not?)

```
      R
    / | \
   L  I  L
     / \
    I   I
   / \ / \
  L  L L  L
```

Parse Trees

May use *parse trees* as compact representation for derivation.

Internal nodes are variables,
Leafs are terminals.

$S \Rightarrow (S) \Rightarrow (SS) \Rightarrow (()S) \Rightarrow (()())$

is a derivation that follows from parse tree on right.

Recall: $S \rightarrow SS \mid (S) \mid ()$

```
       S
      /|\
     ( S )
      / \
     S   S
    / \ / \
   (  )(  )
```

Example: Parenthesized Sums

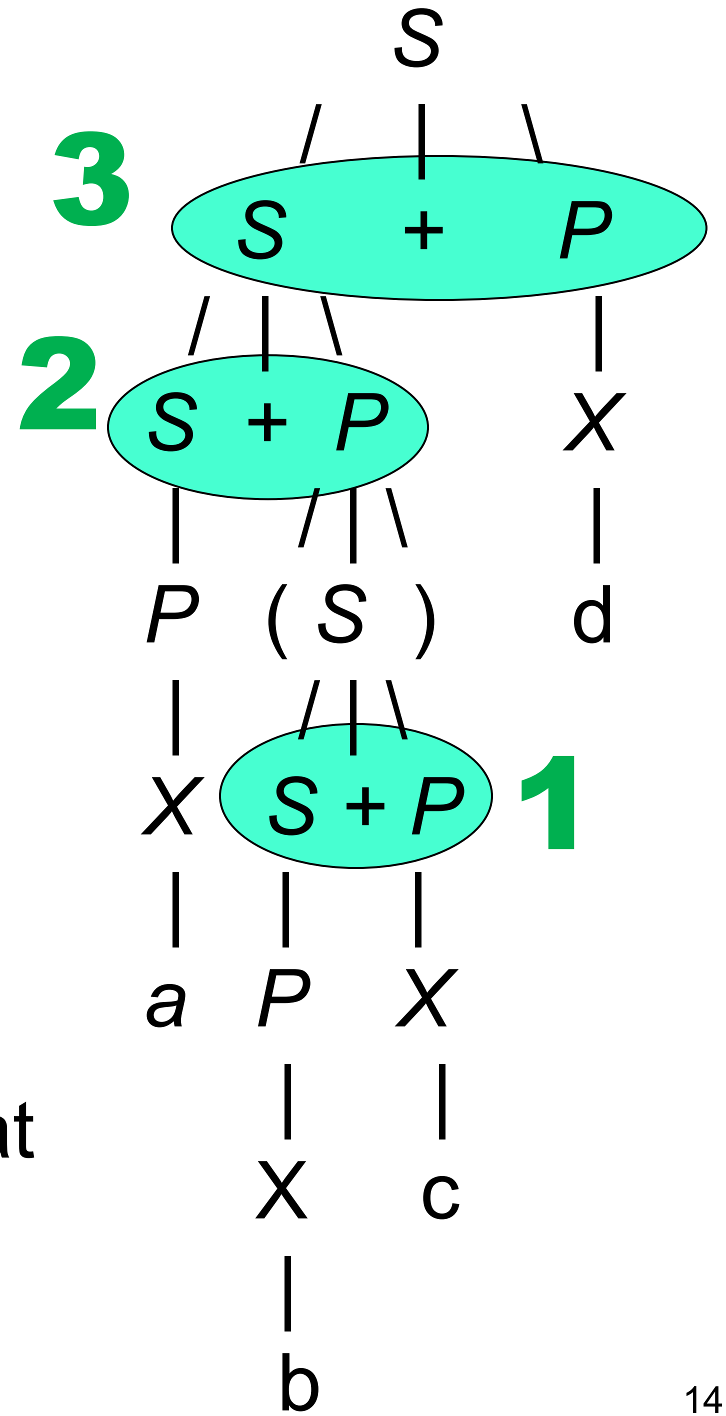
a + b, u, x + (y + z), ...

$G = (V, \Sigma, R, S)$ with

- Variables $V = \{ S, P, X \}$
- Alphabet $\Sigma = \{$ (,), +, a, ..., z $\}$
- Productions:
  $S \rightarrow S + P \mid P$
  $P \rightarrow (S) \mid X$
  $X \rightarrow \text{a} \mid \ldots \mid \text{z}$

$S \rightarrow S + P \mid P$
$P \rightarrow (S) \mid X$
$X \rightarrow \text{a} \mid \ldots \mid \text{z}$

Parse tree for a + (b + c) + d:



Parsing done bottom-up; lower position in parse tree is parsed/evaluated earlier

Parentheses evaluated first

Note that *above rules* imply that + is evaluated left-to-right (*left-associative*)

Note on Notation

Recall: formally, set of productions is a relation.

Can write this in different ways:

Set notation:

$R = \{ (S, SS), (S, (S)), (S, ()) \}$

Verbose arrow notation:

$S \rightarrow SS,\ S \rightarrow (S),\ S \rightarrow ()$

Compact arrow notation:

$S \rightarrow SS \mid (S) \mid ()$

Multiline notation:

S:

SS

(S)

$()$

Context-Free Languages

L is a *context-free language* (CFL),
iff ("if and only if") there exists a CFG G,
such that $L = L(G)$

Example: Is $L_2 = \{ a^n b^n : n \in \mathbb{N} \}$ context-free?

Yes, $L_2 = L((\{ S \}, \{ a, b \}, \{ (S, aSb), (S, \varepsilon) \}, S))$

Example: Is $L_3 = \{ a^n b^n c^n : n \in \mathbb{N} \}$ context-free?

No, there is no CFG G with $L_3 = L(G)$.

Proof: see
https://en.wikipedia.org/wiki/Pumping_lemma_for_context-free_languages

Note: CFLs are a superset of *regular languages*. E.g., L_2 is not regular.

So, is Java context free?

No.

CFGs don't address, e.g., variable declarations/bindings.

But CFGs make the *syntax* precise, which is important both for programmers and parsers.

Backus-Naur Form (*BNF*)

BNF is another notation for CFGs

- Close to compact arrow notation
- Use "::=" instead of arrow, "<...>" for variables

Well-formed parentheses example in BNF:

<*S*> ::= <*S*><*S*> | (<*S*>) | ()

Extended Backus-Naur Form (*EBNF*)

Typically puts terminals into quotes (" or ')

Typically no "<...>" for variables

[*X*] denotes 0 or 1 occurrences of *X*

S ::= a [b] c abbreviates S ::= a c | a b c

{*X*} denotes 0 or more occurrences of *X*

S ::= a {b} c abbreviates S ::= a T c, T ::= b T | ε

(*X*) defines a group

S ::= a (b | c) d abbreviates S ::= a b d | a c d

Java Lexical Grammar

- Is a CFG
- Terminals are from Unicode character set
- Translate into *input symbols* that, with whitespace and comments discarded, form terminal symbols (*tokens*) for *Java Syntactic Grammar*
- Notation is variant of EBNF

See also https://docs.oracle.com/javase/specs/jls/se9/html/jls-2.html#jls-2.4

Example: Java Decimal Numerals

- Want to prohibit leading 0 (except in 0 itself), to avoid clash with octal numeral
- Therefore, must be 0 or begin with non-zero
- Allow underscores, but not at beginning or end

```
DecimalNumeral:
  0
  NonZeroDigit [Digits]
  NonZeroDigit Underscores Digits

NonZeroDigit:
  (one of)
  1 2 3 4 5 6 7 8 9

Digits:
  Digit
  Digit [DigitsAndUnderscores] Digit

DigitsAndUnderscores:
  DigitOrUnderscore {DigitOrUnderscore}

Digit:
  0
  NonZeroDigit

DigitOrUnderscore:
  Digit
  _

Underscores:
  _ {_}
```

https://docs.oracle.com/javase/specs/jls/se9/html/jls-3.html#jls-DecimalNumeral

Expressions

```
int total = n1 + n2;
```

Expression: consists of *terms* (**`n1`**, **`n2`**), or *operands*, joined by *operators* (**`+`**, **`*`**, **`=`**, ...)

Term:
- *Literal*, a.k.a. (*unnamed*) *constant* (**`3.14`**)
- Variable (**`n1`**), including *named constants* (**`PI`**, as in **`static final PI = 3.14`**)
- Method call (**`Math.abs(n1)`**)
- Expression enclosed in parentheses

Primitive Types

Data type: set of values (*domain*) + set of operators

Type	*Domain*	*Common operators*
`byte`	8-bit integers in the range –128 to 127	*The arithmetic operators:* `+` add `*` multiply `–` subtract `/` divide `%` remainder
`short`	16-bit integers in the range –32768 to 32767	
`int`	32-bit integers in the range –2146483648 to 2146483647	*The relational operators:* `==` equal to `!=` not equal `<` less than `<=` less or equal `>` greater than `>=` greater or equal
`long`	64-bit integers in the range –9223372036754775808 to 9223372036754775807	
`float`	32-bit floating-point numbers in the range $\pm 1.4 \times 10^{-45}$ to $\pm 3.4028235 \times 10^{38}$	*The arithmetic operators except* `%` *The relational operators*
`double`	64-bit floating-point numbers in the range $\pm 4.39 \times 10^{-322}$ to $\pm 1.7976931348623157 \times 10^{308}$	
`char`	16-bit characters encoded using Unicode	*The relational operators and* +, -, ...
`boolean`	the values `true` and `false`	*The logical operators:* `&&` and `||` or `!` not *The relational operators:* `==` equal to `!=` not equal

Numbers

This is covered further in Ch. 7

Decimal, binary, octal, hexadecimal notation

$42_{10} = 00101010_2 = 52_8 = 2A_{16}$

K, M, G, T

Decimal: 10^3, 10^6, 10^9, 10^{12}

Binary: 2^{10}, 2^{20}, 2^{30}, 2^{40}

In Java:

Prefix "0"/"0x" means octal/hex literal

$012 \triangleq 10$, $0x12 \triangleq 18$

Aside: Encoding Integers

Computers represent integers in w *bits* $x_i \in \{ 0, 1 \}$

$X = x_{w-1}\, x_{w-2} \ldots x_1\, x_0$

For unsigned int's, X encodes value $B2U(X) = \sum_{i=0}^{w-1} x_i \cdot 2^i$

E.g., $B2U(101) = 1*4 + 0*2 + 1*1 = 5$

For signed int's, X encodes $B2T(X) = -x_{w-1} \cdot 2^{w-1} + \sum_{i=0}^{w-2} x_i \cdot 2^i$

This is *two's complement* encoding

E.g., for w=3, $B2T(101) = –1*4 + 0*2 + 1*1 = –3$

Sign bit

In Java: w = 8 (**`byte`**), 16 (**`short`**/**`char`**), 32 (**`int`**), or 64 (**`long`**)

In Java, all integral types are signed, except for **`char`**

See also https://docs.oracle.com/javase/specs/jls/se9/html/jls-4.html#jls-4.2

Bit-Wise Operators

`byte x = 42;` // **`x`** encoded as $0010\ 1010_2$

`byte y = 15;` // **`y`** encoded as $0000\ 1111_2$

`byte z = -16;` // **`z`** encoded as $1111\ 0000_2$

Bit-wise operators refer to binary encodings

AND: **`x & y`** = 10 // $0000\ 1010_2$

OR: **`x | y`** = 47 // $0010\ 1111_2$

Shift left: **`y << 2`** = 60 // $0011\ 1100_2$

Arithmetic shift right: **`y >> 2`** = 3 // $0000\ 0011_2$

`z >> 2` = -4 // $1111\ 1100_2$

Logical shift right: **`y >>> 2`** = 3 // $0000\ 0011_2$

`z >>> 2` = 60 // $0011\ 1100_2$

More on bit-wise operators in Lecture 7

Abstract Data Types (ADTs)

ADT = set of variables
+ set of operations
+ specification

Specification may be informal prose and/or mathematical equations that must hold (e.g., commutative/distributive/associative laws).

ADT *abstracts* from implementation.

In Java, typically *implement* ADT as class.

Identifiers

Identifier: name of variable, class, method etc.

- Must begin with letter or underscore
- Remaining characters must be letters, digits, or underscores
- Must not be one of Java's reserved words:

`abstract`	**`continue`**	**`for`**	**`new`**	**`switch`**
`assert`	**`default`**	**`goto`**	**`package`**	**`synchronized`**
`boolean`	**`do`**	**`if`**	**`private`**	**`this`**
`break`	**`double`**	**`implements`**	**`protected`**	**`throw`**
`byte`	**`else`**	**`import`**	**`public`**	**`throws`**
`case`	**`enum`**	**`instanceof`**	**`return`**	**`transient`**
`catch`	**`extends`**	**`int`**	**`short`**	**`try`**
`char`	**`final`**	**`interface`**	**`static`**	**`void`**
`class`	**`finally`**	**`long`**	**`strictfp`**	**`volatile`**
`const`	**`float`**	**`native`**	**`super`**	**`while`**

Coding Advice – Naming Conventions

Classes: `UpperCamelCaseNouns`

Methods: `lowerCamelCaseVerbs`

Constants: `UPPER_CASE`

Variables: `lowerCamelCase`

Avoid single-character variable names, except for "temporary" ones:

- integers: `i`, `j`, `k` ...
- char's: `c`, `d`, `e` ...

Try to use English names:
e.g., use `counter` instead of `zaehler`

See also https://en.wikipedia.org/wiki/Naming_convention_(programming)
http://www.oracle.com/technetwork/java/codeconventions-135099.html#367

Variable Variations

Local variable: declared within method

Instance variable (or *non-static field*): declared as part of a class (without **`static`**), one per object

Class variables (or *static field*): declared as part of class (with **`static`**), only one for class

Scoping

Scope: part of program where variable is visible

Scope of local variables: from declaration until end of enclosing *block* (sequence of statements enclosed in braces, see Lec. 4)

Shadowing (or *hiding*): multiple variables of same name have overlapping scope.

In Java:

- local variables shadow fields
  (useful e.g. for *setters*, see later)
- *no* shadowing of local variables
  (local variable names must be unique within method, unlike e.g. for functions in C)

Operators and Operands

Binary operators – take two operands

+, -, /, *, ==, <, >, &&, ||, &, |, ^, <<, >>, ...

Unary operators – take one operand

+, -, ++, --, !

Ternary operator – takes three operands

? :

Type Casts

`int` *op* `int` ⟹ `int`

`int` *op* `double` ⟹ `double`

`double` *op* `double` ⟹ `double`

```
double c = 100;
double f = 9 / 5 * c + 32;
```

Casting: `(`*type*`)` *expression*

```
double f = (double) 9 / 5 * c + 32;
```

Aside: Expression Evaluation

Different operators may be ordered by *precedence*:

An operand between operators of different precedence is bound to operator of higher precedence

* has *higher* precedence than +

```
2 + 3 * 4  == 2 + (3 * 4) !=  (2 + 3) * 4
```

3 bound to *, not to +

Operators of same precedence level ordered by *associativity*:

+ is *left*-associative, operands between +'s bound to left +

```
1 + 1E100 + -1E100 == (1 + 1E100) + -1E100
                   !=  1 + (1E100 + -1E100)
false + true + ""  == (false + true) + ""
                   !=  false + (true + "")
```

1E100/**true** bound to left +, not to right +

See also http://introcs.cs.princeton.edu/java/11precedence/

Level	Operator	Description	Associativity

16	`[]`
	`.`
	`()`
		access array element
		access object member
		parentheses
			left to right

15	`++` `--`	unary post-increment unary post-decrement	not associative

14	`++`
	`--`
	`+`
	`-`
	`!`
	`~`
		unary pre-increment
		unary pre-decrement
		unary plus
		unary minus
		unary logical NOT
		unary bitwise NOT
			right to left

13	`()` `new`	cast object creation	right to left
12	`* / %`	multiplicative	left to right
11	`+ -` `+`	additive string concatenation	left to right

[http://introcs.cs.princeton.edu/java/11precedence/]

10	<< >> >>>	shift	left to right
9	< <= > >= instanceof	relational	not associative
8	== !=	equality	left to right
7	&	bitwise AND	left to right
6	^	bitwise XOR	left to right
5	|	bitwise OR	left to right
4	&&	logical AND	left to right
3	||	logical OR	left to right
2	?:	ternary	right to left
1	= += -= *= /= %= &= ^= |= <<= >>= >>>=	assignment	right to left

[http://introcs.cs.princeton.edu/java/11precedence/]

Aside: Expression Evaluation

Precendence and associativity ...

- govern which operands belong to which operator
- imply paren's
- can be overridden by paren's

Precedence, associativity and paren's tell us how to construct a *fully parenthesized* expression,
which makes all bindings of operands to operators explicit:

```
2 + 3 * (4 + 5)   ==   2 + (3 * (4 + 5))
```

Once expression is fully parenthesized, don't need to consider precedence and associativity any more.

Aside: Expression Evaluation

To perform an operation, we **first** evaluate operands, **then** apply operator to results.

(Special case: short-circuit evaluation for &&, || – see later)

Do this *recursively*: if evaluating an operand entails performing an operation, the same rule applies again.

Operands of operator ordered by *evaluation direction*:

Java evaluates *left-to-right* (undefined in C or C++!)

This matters when operand evaluation has *side effects* (such as assigning new values to variables)

With `i` initially 0: `i + 2 * ++i == 2`

Wait a minute ... `*` has *higher* precedence than `+`, but operands of `*` are evaluated *after* left operand of `+`?

Explanation: evaluation direction, see next slide

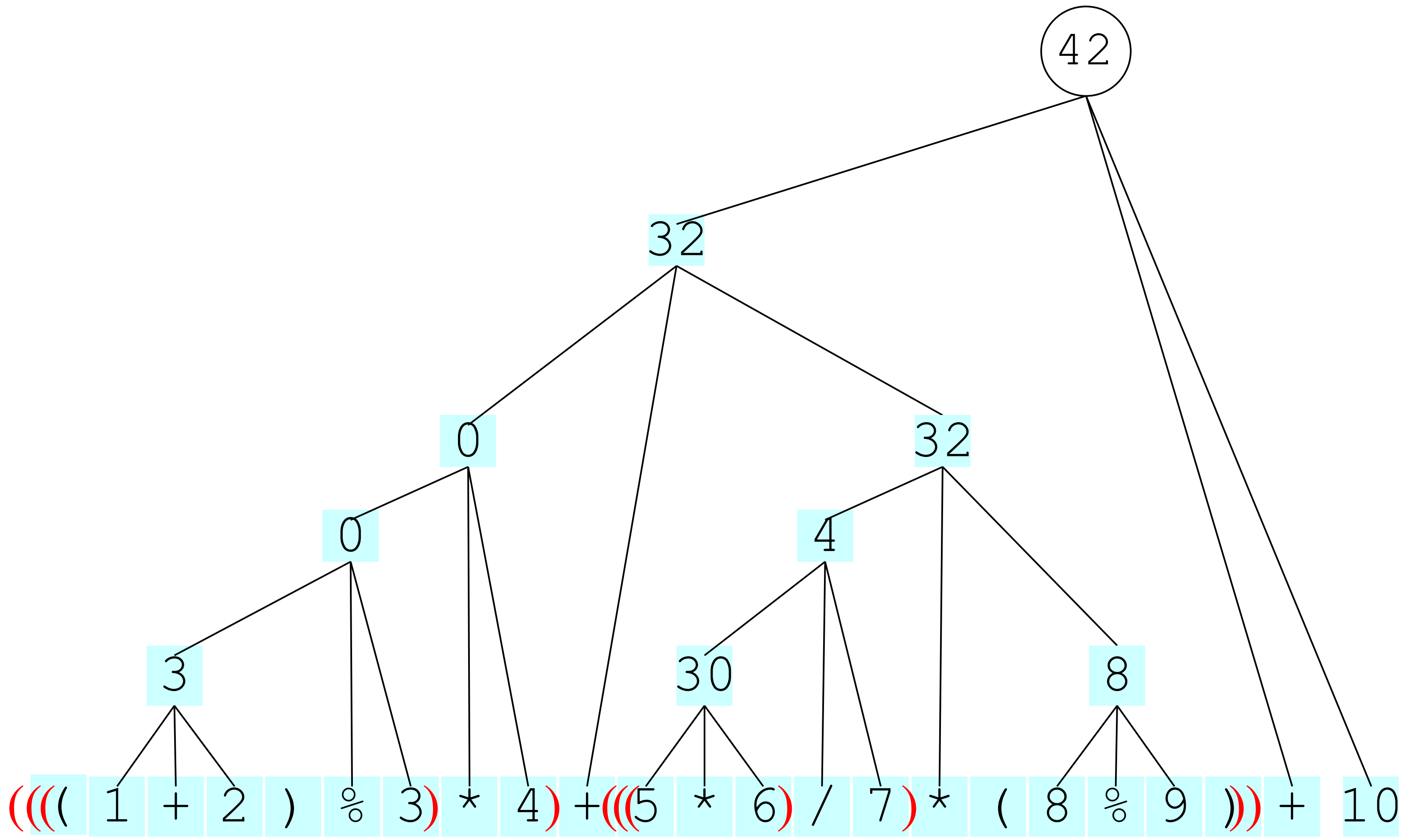
Aside: Expression Evaluation

What happens exactly:

- Fully parenthesized expression: `i + (2 * (++i))`
- We thus have a sum with 2 operands.
- To compute sum, we **first** evaluate the **left** operand, **then** evaluate the **right** operand, **then** compute the sum of both.

1. Evaluating **left** operand `i` yields `0 + (2 * (++i))`
2. **Right** operand `2 * (++i)` is a product, with again 2 operands – thus recursively apply left-to-right rule:
   1. **Left** operand `2` of product is already evaluated: `0 + (2 * (++i))`
   2. Evaluating **right** operand `++i` of product sets `i` to 1 (pre-increment), and yields `0 + (2 * 1)`
   3. Computing **product** yields `0 + 2`
3. Computing **sum** yields `2`

Exercise: Precedence Evaluation



To get started: we have a sum (root of parse tree), whose left operand is another sum, whose left operand is a product, whose left operand is a modulo operation, whose left operand is the sum "**`1 + 2`**".

Coding Advice – Naming, Paren's

- Use meaningful variable names
- Don't use "magic numbers",
  use named constants instead
- Add paren's if precedence may not be obvious

Example: Replace

```
help || me == read && that != thing
```

by

```
help || ((me == read) && (that != thing))
```

Assignments

variable `=` *expression* `;`

Shorthand assignment:

variable *op*`=` *expression* `;`

`int x = 0; x += 1.0;` is equivalent to

`int x = 0; x = (int) (x + 1.0);`

Omitting the `(int)` cast would result in an error

Pre-*increment*

`++`*variable*`;`

`++x;` equivalent to `x += 1;`

`y = ++x;` equivalent to

`x += 1; y = x;`

Post-*increment*

variable`++;`

`x++;` equivalent to `x += 1;`

`y = x++;` equivalent to

`y = x; x += 1;`

Assignment Expressions

- Assignments are also expressions, with assignment operator (=, +=, etc.)
- Left operand must be an “L-Value”, i.e., something that points to a storage location, i.e., a variable
- Assigned value is also value of assignment expression

```
int x, y = (x = 1) + (y = 2) + (x += 3);
```

results in x = 4, y = 7

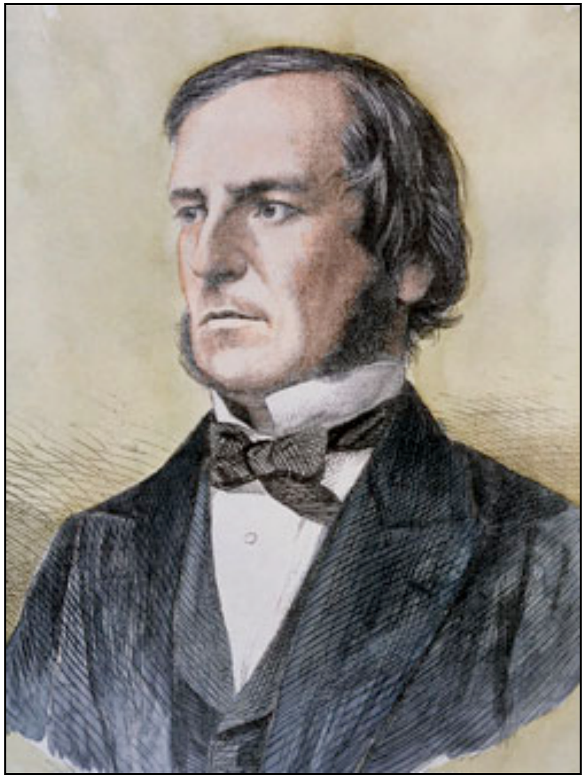
Coding advice: don’t use shorthand assignments (including pre/post-increment etc.) as expressions

Bad: y = x++;

Good: x++; y = x;

Booleans

Boolean values: **`true, false`**



George Boole
(1791-1871)

Logical operators on Booleans:

`&&   ||`

These *short-circuit*:
right operand evaluated only when needed

Other logical operators on Booleans:

`==   !=   !   &   |   ^`

These don't short-circuit

Relational operators producing Booleans:

`<   <=   ==   >=   >   !=`

Coding Advice – Don't confuse "=" and "=="

```
if (oneFlag = otherFlag) {
   ...
}
```

If you *really* mean this, write instead:

```
oneFlag = otherFlag;
if (oneFlag) {
   ...
}
```

But what was *probably* meant:

```
if (oneFlag == otherFlag) {
   ...
}
```

Summary

- Expressions = terms + operators
- Primitive data types: **`int`**, **`double`**, ...
- Simplest terms: constants, variables
- Declarations: ***`type name = value;`***
- Expression evaluation: paren's, precedence, associativity and (in Java) left-to-right evaluation
- Assignments: ***`variable = expression;`***
- Relational operators produce Booleans
- Can operate on Booleans

From Next Week Onwards – We Will Move!

- For both *Vorlesung* and *Globalübung*
- Old: https://uni-kiel.zoom.us/j/85625455567?pwd=SFhGbTcrdGZNVndzenZXdjVmd09GUT09
- New: https://uni-kiel.zoom.us/j/87923834205?pwd=SmV3TDJWWjg2bkIycXVTVWR3blEwUT09