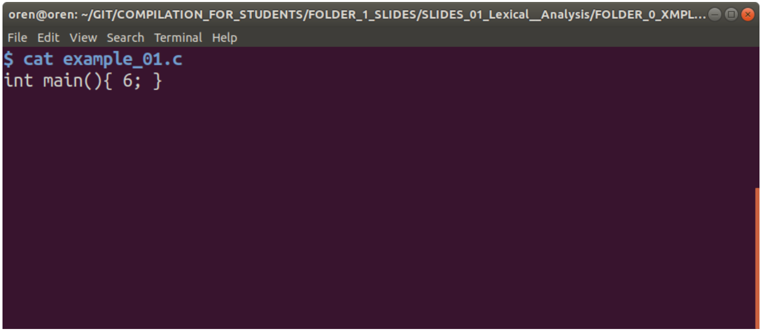
Lexical Analysis

Verifying that every word is legal

November 3, 2019

Warm up examples

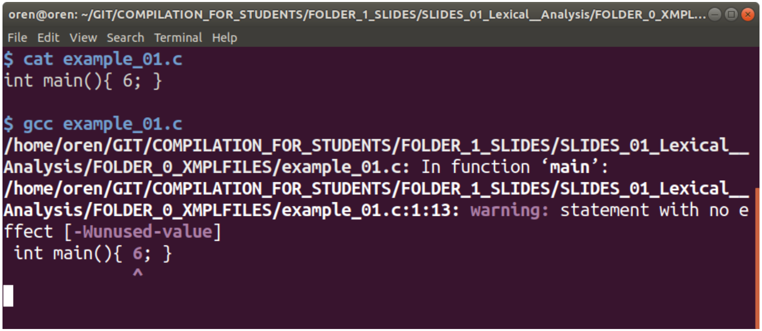
- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ cat example_01.c
int main(){ 6; }
```

Warm up examples

- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
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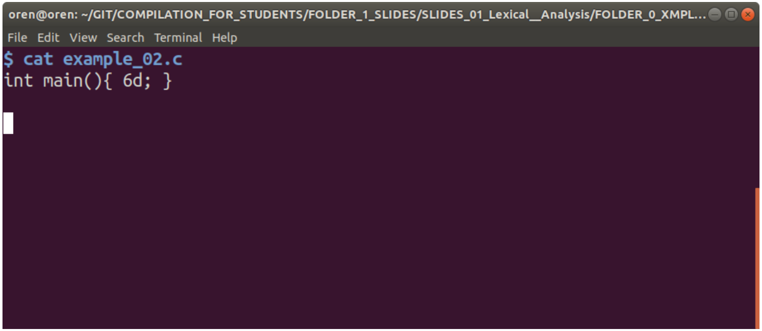
```
$ cat example_01.c
int main(){ 6; }

$ gcc example_01.c
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_01.c: In function ‘main’:
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_01.c:1:13: warning: statement with no e
ffect [-Wunused-value]
 int main(){ 6; }
             ^
```

Warm up examples

- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
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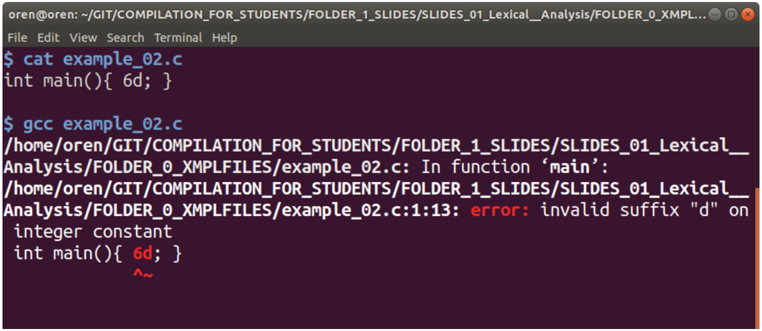
```
$ cat example_02.c
int main(){ 6d; }
```

Warm up examples

- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
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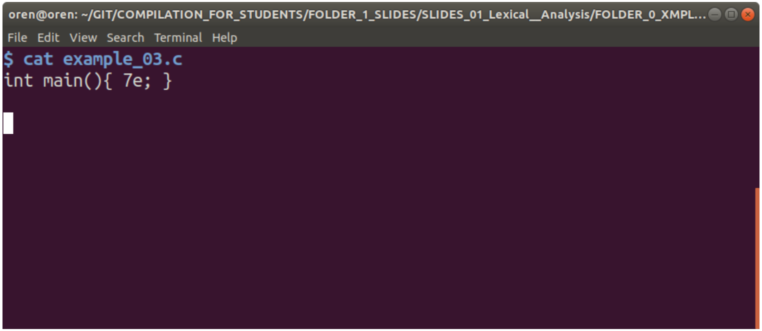
```
$ cat example_02.c
int main(){ 6d; }

$ gcc example_02.c
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_02.c: In function ‘main’:
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_02.c:1:13: error: invalid suffix "d" on
 integer constant
 int main(){ 6d; }
             ^~
```

Warm up examples

- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
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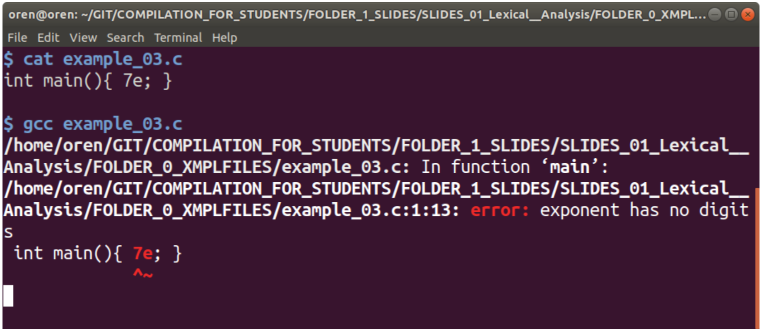
```
$ cat example_03.c
int main(){ 7e; }
```

Warm up examples

- Numbers

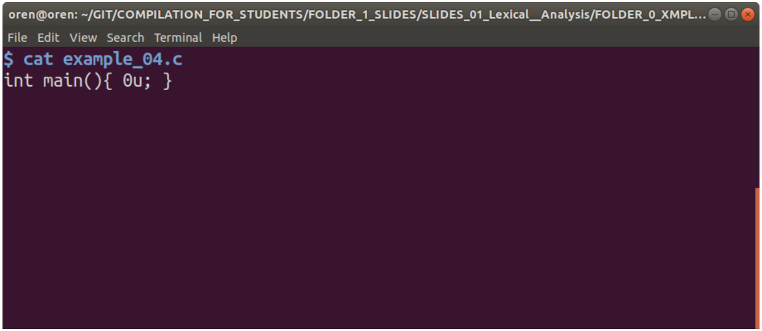

oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ cat example_03.c
int main(){ 7e; }

$ gcc example_03.c
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_03.c: In function ‘main’:
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_03.c:1:13: error: exponent has no digit
s
 int main(){ 7e; }
             ^~
```

Warm up examples

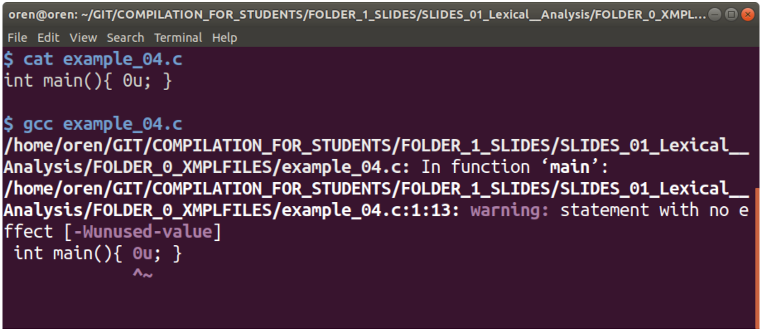
- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ cat example_04.c
int main(){ 0u; }
```

Warm up examples

- Numbers



oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ cat example_04.c
int main(){ 0u; }

$ gcc example_04.c
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_04.c: In function ‘main’:
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_04.c:1:13: warning: statement with no e
ffect [-Wunused-value]
 int main(){ 0u; }
             ^~
```

Warm up examples

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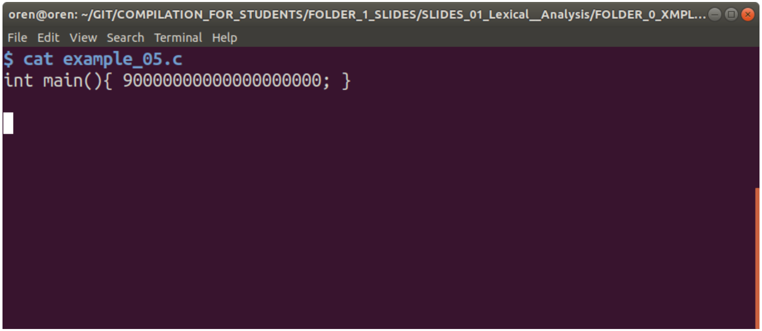
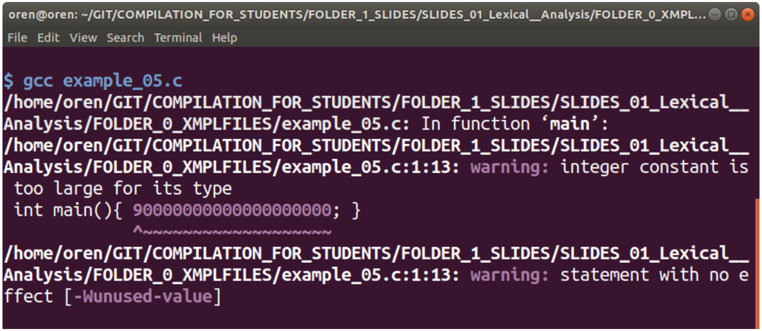

oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ cat example_05.c
int main(){ 90000000000000000000; }
```

Warm up examples

- Numbers


oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ gcc example_05.c
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_05.c: In function ‘main’:
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_05.c:1:13: warning: integer constant is
 too large for its type
 int main(){ 90000000000000000000; }
             ^~~~~~~~~~~~~~~~~~~~
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_05.c:1:13: warning: statement with no e
ffect [-Wunused-value]
```

Warm up examples

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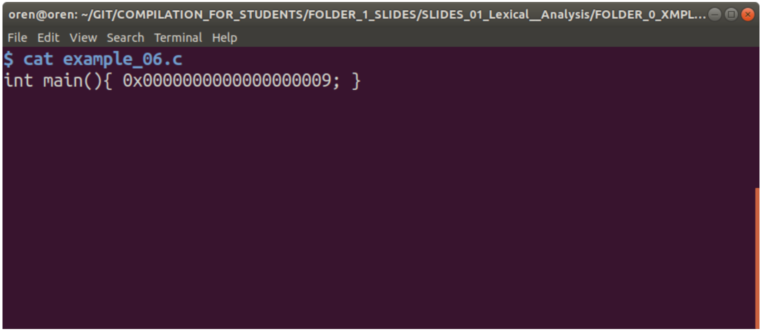
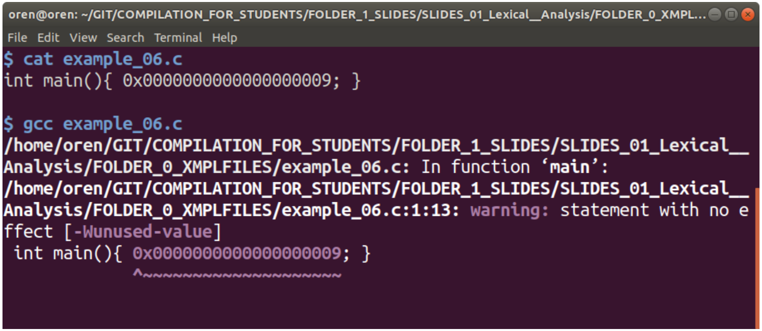

oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help

```
$ cat example_06.c
int main(){ 0x0000000000000000009; }
```

Warm up examples

- Numbers



```
oren@oren: ~/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__Analysis/FOLDER_0_XMPL...
File Edit View Search Terminal Help
$ cat example_06.c
int main(){ 0x000000000000000000009; }

$ gcc example_06.c
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_06.c: In function ‘main’:
/home/oren/GIT/COMPILATION_FOR_STUDENTS/FOLDER_1_SLIDES/SLIDES_01_Lexical__
Analysis/FOLDER_0_XMPLFILES/example_06.c:1:13: warning: statement with no e
ffect [-Wunused-value]
 int main(){ 0x000000000000000000009; }
             ^~~~~~~~~~~~~~~~~~~~~
```

Lexical Analyzer

- The input program is actually a long sentence
- The lexical analyzer verifies each word is legal
- What are the words of programming languages?

Constants	123, 19.7, -700, 13e+8, 0x80, ...
Identifiers	numPoints, doSomething, ...
Reserved Keywords	while, for, int, virtual, class, auto, ...
Parentheses	(,), [,], {, }, ...
Binary Operators	+, -, *, /, ...
Unary Operators	!, ., *, →, ...
Comments	/* bla */, # bla, ; bla, ...

- Once an illegal word is encountered, compilation stops

Lexical Analyzer

- Recall the Google Docs lexical analyzer example here
- Why not do the same thing? simply keep a dictionary
- How many legal words are there (in C for instance)?
- Is keeping a dictionary feasible?
- So how should we specify legal words?
- Specification must be clear for programmers to understand
- Specification must enable a fast validity test for each word
- The answer is regular expressions

Regular Expressions (regex)

- All PLs use regular expressions to specify legal words
  - Python lexical specification here
  - ANSI C lexical specification here
  - JAVA lexical specification here
  - Haskell lexical specification here
  - Scala lexical specification here
- Here is a reminder about regular expressions: wikipedia
- Indeed, it is rather intuitive for human eyes
- How can we test membership fast with regular expressions?
- The answer is regex $\rightarrow$ NFA $\rightarrow$ DFA
- And remember that DFAs are easily programmable

Regex $\rightarrow$ NFA

- Here is a reminder about DFA: wikipedia
- Here is a reminder about NFA: wikipedia
  - Actually, we only need a DFA + ϵ transitions
- Regex to NFA is a simple recursive algorithm
  - Suppose M_i is an NFA representing regex r_i
  - Which NFA represents $r_1 r_2$?
  - Which NFA represents $r_1 | r_2$?
  - Which NFA represents r_1^*?
- Regex to NFA base cases
  - If $r_1 = \text{a}$, what is M_1?
  - If r_1 is the empty set, what is M_1?
  - If r_1 is the empty string, what is M_1?

NFA $\rightarrow$ DFA

- NFA to DFA is a fairly simple iterative algorithm
- Described formally here
- Regex to NFA base cases