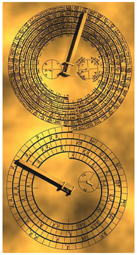
Compilers and Formal Languages (1)



Antikythera automaton, 100 BC (Archimedes?)

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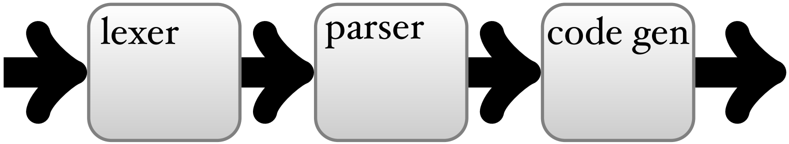
Slides:	KEATS

The Goal of this Course

Write A Compiler



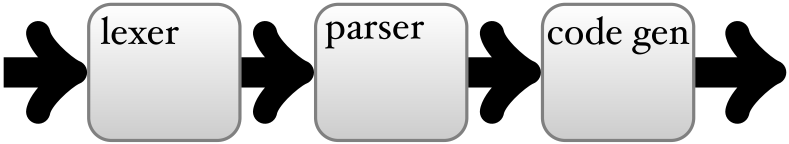
The Goal of this Course

lexer input: a string

```
"read(n);"
```

lexer output: a sequence of tokens

```
key(read); lpar; id(n); rpar; semi
```



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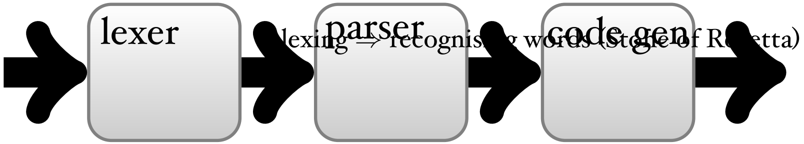
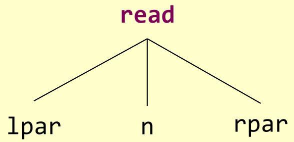
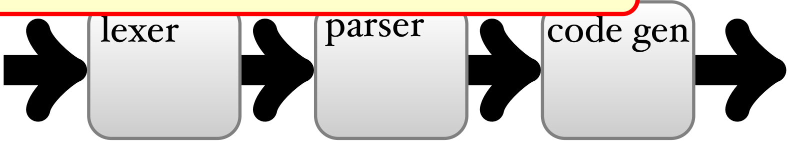


The Goal of this Course

parser input: a sequence of token

parser output: an abstract syntax tree



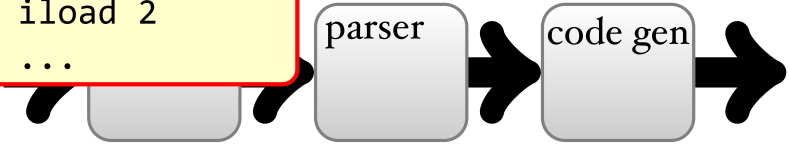


The Goal of this Course

code generator:

```
istore 2
iload 2
ldc 10
isub
ifeq Label2
iload 2
...
```

e A Compiler



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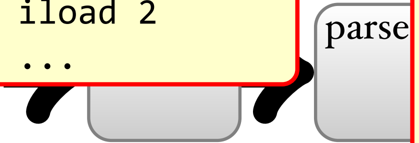
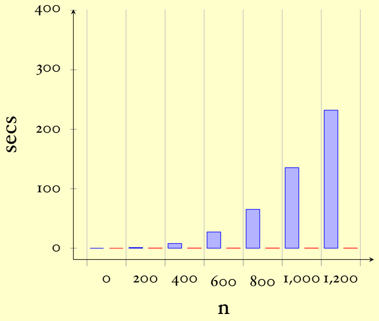




The subject is quite old

- Turing Machines, 1936
- Regular Expressions, 1956
- The first compiler for COBOL, 1957 (Grace Hopper)
- But surprisingly research papers are still published nowadays

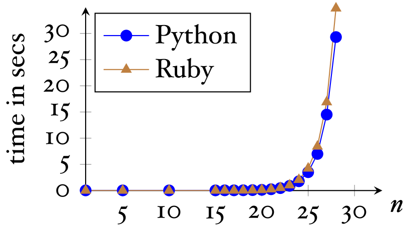
Grace Hopper

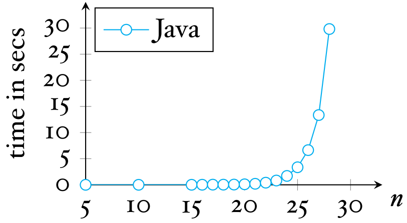
(she made it to David Letterman's Tonight Show,

http://www.youtube.com/watch?v=aZOxtURhfEU)

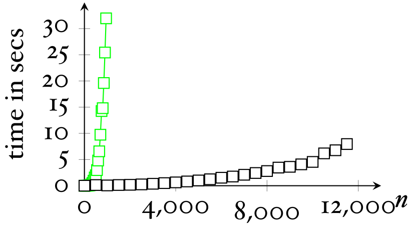
Why Bother?

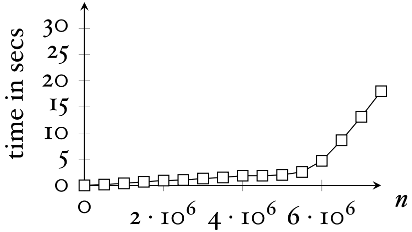
Ruby, Python, Java





Us (after next lecture)





matching `[a?]{n}[a]{n}` and `[a*]*b` against $\underbrace{\texttt{a...a}}_{n}$

Lectures 1 - 5

transforming strings into structured data

Lexing

(recognising "words")

Parsing

(recognising "sentences")

Stone of Rosetta

Lectures 1 - 5

transforming strings into structured data

Lexing based on regular expressions

(recognising “words”)

Parsing Stone of Rosetta

(recognising “sentences”)

Familiar Regular Expr.

```
[a-z0-9_.-]+ @ [a-z0-9.-]+ . [a-z.]{2,6}
```

`re*`	matches 0 or more times
`re+`	matches 1 or more times
`re?`	matches 0 or 1 times
`re{n}`	matches exactly `n` number of times
`re{n,m}`	matches at least `n` and at most `m` times
`[...]`	matches any single character inside the brackets
`[^...]`	matches any single character not inside the brackets
`a-zA-Z`	character ranges
`\d`	matches digits; equivalent to `[0-9]`
`.`	matches every character except newline
`(re)`	groups regular expressions and remembers the matched text

Today

- While the ultimate goal is to implement a small compiler (a really small one for the JVM)...

Let's start with:

- a web-crawler
- an email harvester
- (a web-scraper)

A Web-Crawler

1. given an URL, read the corresponding webpage
2. extract all links from it
3. call the web-crawler again for all these links

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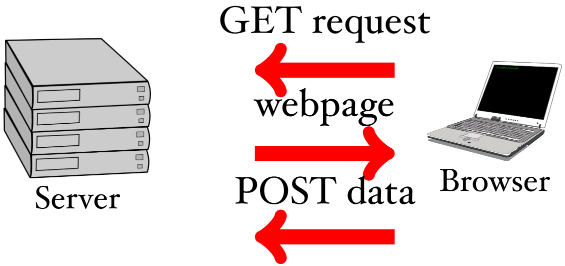
(we need a bound for the number of recursive calls)
(the purpose is to check all links on my own webpage)


GET request
webpage
POST data
Server
Browser

Scala

A simple Scala function for reading webpages:

```
import io.Source

def get_page(url: String) : String = {
  Source.fromURL(url).take(10000).mkString
}
```

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get_page(""""http://www.inf.kcl.ac.uk/staff/urbanc/"""")
```

Scala

A simple Scala function for reading webpages:

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import io.Source

def get_page(url: String) : String = {
  Source.fromURL(url).take(10000).mkString
}

get_page(""""http://www.inf.kcl.ac.uk/staff/urbanc/"""")
```

A slightly more complicated version for handling errors:

```
def get_page(url: String) : String = {
  Try(Source.fromURL(url).take(10000).mkString).
     getOrElse { println(s"  Problem with: $url"); ""}
}
```

Why Scala?

...

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...

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...

$$\text{5 yrs}\left\{\begin{array}{l}\text{2013: 1\%}\\ \text{2014: 3\%}\\ \text{2015: 9\%}\\ \text{2016: 27\%}\\ \text{2017: 81\%}\end{array}\right.$$

2018: 243%

Why Scala?

...

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2018: 243%

in London today: 1 Scala job for every 30 Java jobs;
Scala programmers seem to get up to 20% better salary

Why Scala?

Scala is a functional and object-oriented programming language; compiles to the JVM; does not need null-pointer exceptions; a course on Coursera

`http://www.scala-lang.org`

...

2016: 27%
2017: 81%
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in London today: 1 Scala job for every 30 Java jobs; Scala programmers seem to get up to 20% better salary

A Regular Expression

- ... is a pattern or template for specifying strings

```
”https?://[^”]*”
```

matches for example

```
”http://www.foobar.com”
”https://www.tls.org”
```

A Regular Expression

- ... is a pattern or template for specifying strings

```
””””https?://[^”]*””””.r
```

matches for example

```
”http://www.foobar.com”
”https://www.tls.org”
```

Finding Operations

`rexp.findAllIn(string)`

returns a list of all (sub)strings that match the regular expression

`rexp.findFirstIn(string)`

returns either

- `None` if no (sub)string matches or
- `Some(s)` with the first (sub)string

```
val http_pattern = """"https?://[^"]*"""".r

def unquote(s: String) = s.drop(1).dropRight(1)

def get_all_URLs(page: String) : Set[String] =
  http_pattern.findAllIn(page).map(unquote).toSet

def crawl(url: String, n: Int) : Unit = {
  if (n == 0) ()
  else {
    println(s"Visiting: $n $url")
    for (u <- get_all_URLs(get_page(url))) crawl(u, n - 1)
  }
}

crawl(some_start_URL, 2)
```

A version that only crawls links in "my" domain:

```
val my_urls = """urbanc""".r

def crawl(url: String, n: Int) : Unit = {
  if (n == 0) ()
  else if (my_urls.findFirstIn(url) == None) {
    println(s"Visiting: $n $url")
    get_page(url); ()
  }
  else {
    println(s"Visiting: $n $url")
    for (u <- get_all_URLs(get_page(url))) crawl(u, n - 1)
  }
}
```

A little email harvester:

```
val http_pattern = """https?://[^"]*""".r
val email_pattern =
  """([a-z0-9_\.-]+)@([\da-z\.-]+)\.([a-z\.]{2,6})""".r

def print_str(s: String) =
  if (s == "") () else println(s)

def crawl(url: String, n: Int) : Unit = {
  if (n == 0) ()
  else {
    println(s"Visiting: $n $url")
    val page = get_page(url)
    print_str(email_pattern.findAllIn(page).mkString("\n"))
    for (u <- get_all_URLs(page).par) crawl(u, n - 1)
  }
}
```

http://net.tutsplus.com/tutorials/other/8-regular-expressions-you-should-know/

Regular Expressions

Their inductive definition:

r	$::=$	$\mathbf{0}$	null
	$\mid$	$\mathbf{1}$	empty string / "" / []
	$\mid$	c	character
	$\mid$	$r_1 + r_2$	alternative / choice
	$\mid$	$r_1 \cdot r_2$	sequence
	$\mid$	r^*	star (zero or more)

Th

```
abstract class Rexp
case object ZERO extends Rexp
case object ONE extends Rexp
case class CHAR(c: Char) extends Rexp
case class ALT(r1: Rexp, r2: Rexp) extends Rexp
case class SEQ(r1: Rexp, r2: Rexp) extends Rexp
case class STAR(r: Rexp) extends Rexp
```

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Regular Expressions

In Scala:

```
def OPT(r: Rexp) = ALT(r, ONE)

def NTIMES(r: Rexp, n: Int) : Rexp = n match {
  case 0 => ONE
  case 1 => r
  case n => SEQ(r, NTIMES(r, n - 1))
}
```

Strings

...are lists of characters. For example `"hello"`

$$[h, e, l, l, o] \text{ or just } hello$$

the empty string: $[]$ or $""$

the concatenation of two strings:

$$s_1 @ s_2$$

$foo @ bar = foobar,\ baz @ [] = baz$

Languages, Strings

- **Strings** are lists of characters, for example

  $[], abc$ (Pattern match: $c::s$)

- A **language** is a set of strings, for example

  $$\{[], hello, foobar, a, abc\}$$

- **Concatenation** of strings and languages

  $$foo\,@\,bar = foobar$$

  $$A\,@\,B \stackrel{\text{def}}{=} \{s_1\,@\,s_2 \mid s_1 \in A \wedge s_2 \in B\}$$

The Meaning of a Regular Expression

$$\begin{array}{rcl}
L(\mathbf{0}) & \overset{\text{def}}{=} & \{\} \\
L(\mathbf{1}) & \overset{\text{def}}{=} & \{[]\} \\
L(c) & \overset{\text{def}}{=} & \{[c]\} \\
L(r_1 + r_2) & \overset{\text{def}}{=} & L(r_1) \cup L(r_2) \\
L(r_1 \cdot r_2) & \overset{\text{def}}{=} & \{s_1 @ s_2 \mid s_1 \in L(r_1) \wedge s_2 \in L(r_2)\} \\
L(r^*) & \overset{\text{def}}{=} &
\end{array}$$

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(append on sets)

$\{s_1 @ s_2 \mid s_1 \in L(r) \wedge s_2 \in L(r)^n\}$

The Meaning of a Regular Expression

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L(r^*) &\overset{\text{def}}{=} \bigcup_{0 \leq n} L(r)^n
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$$
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The Meaning of Matching

A regular expression r matches a string s provided

$$s \in L(r)$$

...and the point of the next lecture is to decide this problem as fast as possible (unlike Python, Ruby, Java)

Written Exam

- Accounts for 80%.
- You will understand the question "*Is this relevant for the exam?*" is very demotivating for the lecturer!
- Deal: Whatever is in the homework (and is not marked "*optional*") is relevant for the exam.
- Each lecture has also a handout. There are also handouts about notation and Scala.

Coursework

- Accounts for 20%. Two strands. Choose **one**!

Strand 1

- four programming tasks:
  - matcher (4%, 20.10.)
  - lexer (5%, 03.11.)
  - parser (5%, 24.11.)
  - compiler (6%, 13.12.)

Strand 2

- one task: prove the correctness of a regular expression matcher in the Isabelle theorem prover
- 20%, submission 13.12.

- Solving more than one strand will **not** give you more marks.
- The exam will contain in much, much smaller form elements from both (but will also be in lectures and HW).

Questions?