Finite State Morphology Tutorial

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CLT 09, Lahore
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- Theory of Finite State Morphology
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  - building networks with xfst

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The Lexicon

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- **Practical application of Finite State Morphology**
Finite State Morphology - The Book

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- Xerox finite-state tools and techniques for morphological analysis and generation
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  - lexc → high-level language for specifying lexicons
  - xfst → a) interface providing regular-expression compiler
    b) access to the Xerox Finite State Calculus
- runtime applications tokenize and lookup
A Short Look at the Xfst Interface

xfst[3]:

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→ Stack operations will be introduced later
The Goal of the Book is to teach ... 

- ... linguists how to use the tools and techniques.
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- the formal properties of finite state networks.
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- linguists how to use the tools and techniques.
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- to build useful and efficient programs that process text in natural languages.
Applications of the software

1. **Tokenization** divides a running input text into tokens
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Morphological Application

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2. **PHONOLOGICAL/ORTHOGRAPHICAL ALTERNATIONS**: spelling/sound of a morpheme often depends on its environment.
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   - Therefore it is *piti-less* instead of *pity-less*
Finite State Networks — Acceptor
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Finite State Networks — optimized Acceptor

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... and space and running time can be saved, which makes the networks rather quick.
Finite State Networks — Acceptor

This type network is called an *Acceptor*. 

![Finite State Network Diagram](Accept2.dot)
Finite State Networks — Acceptor

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- There is always an **upper** (analysis) and a **lower** (generation) side to the network.
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car
xfst[1]: down car
car
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Finite State Networks — Transducer

In order to work with morphological analysis/generation, Transducers are very useful:

In \textit{xfst}-terms, this means:

\begin{verbatim}
xfst[1]: up cars
car+pl
xfst[1]: down car+pl
cars
\end{verbatim}
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![Finite State Machine Diagram]

Trans.dot
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Practical application of Finite State Morphology
Basic Ingredients

1. Lexicon: which contains the stems, the inflectional or derivational morphemes, and the appropriate morphological analysis.

2. Regular expressions: which manipulate the forms of the lexicon on the basis of phonological rules.

3. Executable Script — short: Script: which saves you a lot of typing.
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For an already very powerful finite state automata, one needs

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  +Pl +Sg
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Basic idea: The Lexicon contains different states for each morpheme.

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  LEXICON Root
  
  cat    SgPl;
  car    SgPl;
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- followed by the different Lexicons, starting out with Lexicon Root, the start state:
  
  Lexicon Root
  cat      SgPl;
  car      SgPl;

Here, the stems are included. The next Lexicon is indicated by the made-up SgPl at the end followed by a semicolon.
The Lexicon

The Automata now jumps to the next state/lexicon called $\text{SgPl}$. 
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\begin{verbatim}
LEXICON SgPl

  +Pl:s   #;
  +Sg:0   #;
\end{verbatim}
The Lexicon

The Automata now jumps to the next state/lexicon called SgPl.

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LEXICON SgPl
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  +Sg:0  #;
```

→ The left side of the colon represents the *upper* (the analysis) side of the transducer.
The Lexicon

The Automata now jumps to the next state/lexicon called SgPl.

LEXICON SgPl

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→ The left side of the colon represents the *upper* (the analysis) side of the transducer.

→ The right side shows the *lower* side (the generation/surface form).
The Lexicon

The Automata now jumps to the next state/lexicon called SgPl.

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LEXICON SgPl
  +Pl:s #;
  +Sg:0 #;
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The surface morpheme on the right side is connected to the analysis on the left side.
The Lexicon

The Automata now jumps to the next state/lexicon called $SGPL$.

\[
\text{LEXICON } SgPl
\]

\[
+P1:s \ #; \\
+Sg:0 \ #;
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The surface morpheme on the right side is connected to the analysis on the left side.

In this case, $+P1$ is connected to $[-s]$. $+Sg$ however, is represented by a Null-morpheme.
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→ The hash symbol at the end of the row indicates the end of the path - this Lexicon is therefore the *final state*. 
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Multichar_symbols

+P1 +Sg +N +A
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LEXICON Root
  milk       Noun;
  car        Noun;
  pity       Noun;
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    Adj;

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+P1:s #;
+Sg:0 #;

LEXICON Adj
+Adj:less #;
The Script — Calling up the Lexicon

The **Script** (*script.xfst*) is a source code — avoids too much typing at the interface:

```
Our first entry will be clear which ensures that there are no "leftovers" on the stack
In order to open up the Lexicon, we add:
read lexc < testlex.txt
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Back to the Lexicon...
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The Lexicon — Overgeneration

However, the current LEXICON does allow a lot of overgeneration.

1. *milkless* → The noun milk cannot become an adjective by means of the suffix -less.
2. *milks* and *pitys* → Both nouns are uncountable (no Plurals).
3. *pityless* → A phonological rule is needed for correct spelling: pitiless.
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Root...3, Noun...2, SqPl...2, Adj...1
Building lexicon...Minimizing...Done!
1.6 Kb. 15 states, 18 arcs, 9 paths.
Closing 'testlex.txt'
xfst[1]: print lower-words
milkless
milks
milk
carless
cars
car
pityless
pitys
pity

xfs[1]:
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The Lexicon — Flags

1. and 2. can be solved by manipulating the Lexicon itself.

There are two possibilities:

More paths/lexicons can be added

So-called Flag Diacritics can be integrated

These flags can be imagined as invisible markers that are added to strings. Other flags are stop signs, which will allow only certain strings and their flags to pass through.
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The Lexicon — Types of Flags

Generally, flags are split into three parts:

- **Name**: Flag-names usually consist of only one letter, three of the possibilities are listed below
  - P → Positive: marks the flag as carrying that specific feature-value pair
  - R → Requires that feature-value pair on a string to open up this path
  - D → Disallows that specific feature-value pair on a string to pass

- **Feature**: The features can be invented individually. They often describe a certain grammatical category like case or number.

- **Value**: Values are the specific shapes of the grammatical categories, e.g. Sg, Pl, Dat or Acc.
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  - P → Positive: marks the flag as carrying that specific feature-value pair
  - R → Requires that feature-value pair on a string to open up this path
  - D → Disallows that specific feature-value pair on a string to pass

- **Feature**: The features can be invented individually. They often describe a certain grammatical category like case or number.

- **Value**: Values are the specific shapes of the grammatical categories, e.g. Sg, Pl, Dat or Acc.
The Lexicon — Flags

The Lexicon with Flag Diacritics:
The Lexicon — Flags

The Lexicon with **Flag Diacritics**:

```plaintext
Multichar_Symbols
+Sg +Pl +N +Ä
@P.LIQUID.yes@ @D.LIQUID@
@P.COUNT.yes@ @R.COUNT.yes@

LEXICON Root
milk@P.LIQUID.yes@       Noun;
car@P.COUNT.yes@         Noun;
pity                    Noun;

LEXICON Noun
+N:0                      SqPl;
@D.LIQUID@                Adj;

LEXICON SqPl
< "+Pl":s "@R.COUNT.yes@" > #;
+Sg:0                     #;

LEXICON Adj
+A:less                   #;
```
The Lexicon — Flags

The Lexicon with Flag Diacritics:

```
Multichar_Symbols
+Sg +Pl +N +Ä
@P.LIQUID.yes@ @D.LIQUID@
@P.COUNT.yes@ @R.COUNT.yes@

LEXICON Root
milk@P.LIQUID.yes@ Noun;
car@P.COUNT.yes@ Noun;
pity

LEXICON Noun
+N:OSqPl;
@D.LIQUID@ Adj;

LEXICON SqPl
< "+Pl":s "@R.COUNT.yes@" > #;
+Sg:O #;

LEXICON Adj
+A:less #;
```

However, whenever you include flags into your LEXICON, remember to eliminate these after your compilation...
The Lexicon — Flag Elimination

.... but why?
The Lexicon — Flag Elimination

.... but why?

→ difficult manipulation via Regular Expressions
The Lexicon — Flag Elimination

.... but why?

→ difficult manipulation via Regular Expressions

→ consider the following output:
The Lexicon — Flag Elimination

.... but why?

→ difficult manipulation via **Regular Expressions**

→ consider the following output:

```bash
xfst[0]: read lexc < testlex.txt
Reading from 'testlex.txt'
Root...3, Noun...2, SgPl...2, Adj...1
Building lexicon...Minimizing...Done!
1.7 Kb. 19 states, 22 arcs, 9 paths.
Closing 'testlex.txt'
xfst[1]: print lower-words
milk
car
pity
pityless
xfst[1]: set show-flags ON
variable show-flags = ON
xfst[1]: print lower-words
milk@P.LIQUID.yes@
car@P.COUNT.yes@@ER.COUNT.yes@
car@P.COUNT.yes@
car@P.COUNT.yes@@O.LIQUID@less
pity
pity@E.LIQUID@less
xfst[1]: eliminate flag COUNT
1.7 Kb. 19 states, 23 arcs, 7 paths.
xfst[1]: eliminate flag LIQUID
1.5 Kb. 18 states, 22 arcs, 6 paths.
xfst[1]: print lower-words
pityless
pity
milk
car
```

Miriam Butt and Tina Bögel (Konstanz)
We already have two commands in our `script.xfst`:

```
clear
read lexc < testlex.txt
```
The Script — Eliminating flags

We already have two commands in our script.xfst:

```
clear
read lexc < testlex.txt
```

- To eliminate the flags simply list the different features:
The Script — Eliminating flags

We already have two commands in our script.xfst:

```
clear
read lexc < testlex.txt
```

- To eliminate the flags simply list the different features:

```
eliminate flag LIQUID
```
We already have two commands in our script.xfst:

clear
read lexc < testlex.txt

- To eliminate the flags simply list the different features:

eliminate flag LIQUID
eliminate flag COUNT
The Script — Eliminating flags

We already have two commands in our script.xfst:

```
clear
read lexc < testlex.txt
```

- To eliminate the flags simply list the different features:
  
  ```
  eliminate flag LIQUID
  eliminate flag COUNT
  ```

- This will cover all of our four flags
The Lexicon — Output with Flags

With flags, the output of our current LEXICON will look like the following:

*milks, *pitys
*and *milkless

...but what about *pit???
The Lexicon — Output with Flags

With flags, the output of our current LEXICON will look like the following:

```bash
xfst[1]: source script.xfst
Opening file script.xfst...
Reading from 'testlex.txt'
Root...3, Noun...2, SgPl...2, Adj...1
Building lexicon...Minimizing...Done!
1.7 Kb. 19 states, 22 arcs, 9 paths.
Closing 'testlex.txt'
1.7 Kb. 18 states, 21 arcs, 8 paths.
1.6 Kb. 18 states, 22 arcs, 6 paths.
Closing file script.xfst...
xfst[1]: print lower-words
pity
pityless
milk
  cars
  car
  carless
xfst[1]: print upper-words
pity+N+Sg
pity+A
milk+N+Sg
car+N+Pl
car+N+Sg
car+A
xfst[1]: 
```
The Lexicon — Output with Flags

With flags, the output of our current **LEXICON** will look like the following:

```
xfst[1]: source script.xfst
Opening file script.xfst...
Reading from 'testlex.txt'
Root...3, Noun...2, SgPl...2, Adj...1
Building lexicon...Minimizing...Done!
1.7 Kb. 19 states, 22 arcs, 9 paths.
Closing 'testlex.txt'
1.7 Kb. 18 states, 21 arcs, 8 paths.
1.6 Kb. 18 states, 22 arcs, 6 paths.
Closing file script.xfst...
xfst[1]: print lower-words
pity
pityless
milk
cars
car
carless
```
```
xfst[1]: print upper-words
pity+N+Sg
pity+A
milk+N+Sg
car+N+Pl
car+N+Sg
car+A
```

* `milks`, * `pitys` and * `milkless` have disappeared...
The Lexicon — Output with Flags

With flags, the output of our current LEXICON will look like the following:

```
xfst[1]: source script.xfst
Opening file script.xfst...
Reading from 'testlex.txt'
Root...3, Noun...2, SgPl...2, Adj...1
Building lexicon...Minimizing...Done!
1.7 Kb. 19 states, 22 arcs, 9 paths.
Closing 'testlex.txt'
1.7 Kb. 18 states, 21 arcs, 8 paths.
1.6 Kb. 18 states, 22 arcs, 6 paths.
Closing file script.xfst...
xfst[1]: print lower-words
pity
pityless
milk
cars
car
carless
```

* milks, * pitys and * milkless have disappeared...

... but what about * pity/less ???
Theory of Finite State Morphology
  - some facts — the book & the software
  - some basic knowledge — finite state morphology
  - building networks with xfst
    - The Lexicon
    - Regular Expressions
    - The Interface
  - possible applications

Practical application of Finite State Morphology
Regular Expressions

*pity*less needs to be dealt with by Regular Expressions.
*pityless needs to be dealt with by Regular Expressions.

Languages that can be described in finite state are those, which can be described by Regular Expressions.
Regular Expressions

*pityless* needs to be dealt with by Regular Expressions.

Languages that can be described in finite state are those, which can be described by Regular Expressions.

- describes a string \( a \) (for a simple acceptor) or
*pityless* needs to be dealt with by Regular Expressions.

Languages that can be described in finite state are those, which can be described by Regular Expressions.

- describes a string **a** (for a simple acceptor) or
- a relation **a:a** (for a transducer) and
*pityless* needs to be dealt with by Regular Expressions.

Languages that can be described in finite state are those, which can be described by Regular Expressions.

- describes a string \(a\) (for a simple acceptor) or
- a relation \(a:a\) (for a transducer) and
- can be compiled into a finite network
Some basic **Regular Expressions** — mainly following classical computer science:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Epsilon</td>
</tr>
<tr>
<td>?</td>
<td>Any Symbol</td>
</tr>
<tr>
<td>.#.</td>
<td>Boundary Symbol</td>
</tr>
<tr>
<td>()</td>
<td>Optionality</td>
</tr>
<tr>
<td>+</td>
<td>Concatenation with itself one or more times</td>
</tr>
<tr>
<td>*</td>
<td>Concatenation with itself zero or more times</td>
</tr>
<tr>
<td>~</td>
<td>Negation</td>
</tr>
<tr>
<td>_</td>
<td>Place holder</td>
</tr>
<tr>
<td>{ }</td>
<td>Concatenation</td>
</tr>
<tr>
<td>[ ]</td>
<td>Grouping</td>
</tr>
<tr>
<td>→</td>
<td>Becomes...</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>.o.</td>
<td>Composition</td>
</tr>
</tbody>
</table>

---

Miriam Butt and Tina Bögel (Konstanz)
Regular Expressions — An Example

With an abstract example like:

\[
[ \{ab\} c .x. \{de\} f^* g] 
\]

what would I get as output?
Regular Expressions — An Example

With an abstract example like:

$$\left[ \{ab\} \ c \ .x. \ \{de\} \ f^* \ g \right]$$

what would I get as output?

```
xfst[0]: read regex [ {ab} c .x. {de} f* g ];
264 bytes. 5 states, 6 arcs, Circular.
xfst[1]: print words
   <a:d><b:e><c:g>
   <a:d><b:e><c:f><0:g>
xfst[1]: print random-lower
   deffg
defg
deffg
deffg
deffg
deffg
defg
defg
defg
deffg
deffg
deffg

xfst[1]: print random-upper
   abc
   abc
   abc
   abc
   abc
   abc
   abc
   abc
   abc
   abc
   abc
   abc
```

Miriam Butt and Tina Bögel (Konstanz)
Regular Expressions — *pityless

Regular Expressions are mostly used to manipulate the Lexicon phonologically. In the case of *pityless, the phonological rule would be:

\[ y \rightarrow i \mid \text{less} \]

which translates as

‘y’ becomes ‘i’ iff ‘less’ follows ‘y’
Regular Expressions — The File

The phonological rules (and other Regular Expressions) are kept in a separate file: testrules.regex. Here, they are used by means of composition:
Regular Expressions — The File

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Regular Expression 1
.o.
Regular Expression 2
.o.
Regular Expression 3;
The phonological rules (and other Regular Expressions) are kept in a separate file: testrules.regex. Here, they are used by means of composition:

Regular Expression 1
.o.
Regular Expression 2
.o.
Regular Expression 3;

Be aware of the fact that the second rule will take as the input the output of the first rule etc. (feeding and bleeding).
Regular Expressions — The File

The phonological rules (and other Regular Expressions) are kept in a separate file: testrules.regex. Here, they are used by means of composition:

Regular Expression 1
  .o.
Regular Expression 2
  .o.
Regular Expression 3;

- Be aware of the fact that the second rule will take as the input the output of the first rule etc. (feeding and bleeding).
- The correct succession of phonological rules is therefore of great importance.
The Script — Introducing the Regular Expressions

We already have four commands in our script.xfst:

clear
read lexc < testlex.txt
eliminate flag LIQUID
eliminate flag COUNT
We already have four commands in our `script.xfst`:

```
clear
read lexc < testlex.txt
eliminate flag LIQUID
eliminate flag COUNT
```

In order to introduce the **Regular Expressions** we need to add another entry:
We already have four commands in our script.xfst:

clear
read lexc < testlex.txt
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In order to introduce the Regular Expressions we need to add another entry:

read regex < testrules.regex
Theory of Finite State Morphology
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  - The Interface
- possible applications

Practical application of Finite State Morphology
The Interface

The xfst-INTERFACE is used to interact with the different files but also to accomplish smaller tasks directly.

1. **pop stack** \(\rightarrow\) will take away the top network
2. **turn stack** \(\rightarrow\) will turn the stack around
3. **apply up/down word** \(\rightarrow\) analyse/generate a certain string
4. **compose/concatenate/union net** \(\rightarrow\) see Regular Expressions
The Interface

The xfst-INTERFACE is used to interact with the different files but also to accomplish smaller tasks directly.

- The stack takes the networks as they come: the last one is on top.

xfst[3]:

```bash
xfst
```
The Interface

The xfst-INTERFACE is used to interact with the different files but also to accomplish smaller tasks directly.

- The stack takes the networks as they come: the last one is on top.
  
  \[ \text{xfst}[3] : \]

- There are certain stack operations that help to manipulate the network:

  \[ \text{1. pop stack} \rightarrow \text{will take away the top network} \]

  \[ \text{2. turn stack} \rightarrow \text{will turn the stack around} \]

  \[ \text{3. apply up/down word} \rightarrow \text{analyse/generate a certain string} \]

  \[ \text{4. compose/concatenate/union net} \rightarrow \text{see Regular Expressions} \]
The Interface

The **xfst-INTERFACE** is used to interact with the different files but also to accomplish smaller tasks directly.

- The *stack* takes the networks as they come: the last one is on top.
  
  \[
  \text{xfst}[3]:
  \]

- There are certain *stack operations* that help to manipulate the network:
  
  1. **pop stack** → will take away the top network
The Interface

The xfst-INTERFACE is used to interact with the different files but also to accomplish smaller tasks directly.

- The stack takes the networks as they come: the last one is on top.

  \[ \text{xfst}[3] \]

- There are certain stack operations that help to manipulate the network:
  1. pop stack \( \rightarrow \) will take away the top network
  2. turn stack \( \rightarrow \) will turn the stack around
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  \text{xfst}[3]:
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- There are certain stack operations that help to manipulate the network:
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The **xfst-INTERFACE** is used to interact with the different files but also to accomplish smaller tasks directly.

- The *stack* takes the networks as they come: the last one is on top.
  
  \[ \text{xfst}[3] : \]

- There are certain *stack operations* that help to manipulate the network:
  
  1. **pop stack** → will take away the top network
  2. **turn stack** → will turn the stack around
  3. **apply up/down word** → analyse/generate a certain string
  4. **compose/concatenate/union net** → see **Regular Expressions**

- In order to combine our rules and our lexicon, we need the *composition*-operator
Some thoughts about **Composition**
Some thoughts about **Composition**

- Our testrules.regex need an input they can work with
The Interface — Composing our Networks

Some thoughts about Composition

- Our testrules.regex need an input they can work with
- Therefore they need to be at the second position of the composing process
The Interface — Composing our Networks

Some thoughts about **Composition**

- Our testrules.regex need an input they can work with
- Therefore they need to be at the second position of the composing process

\[
\text{LEXICON} \rightarrow *\text{pityless} \rightarrow \text{RULES} \rightarrow \text{piti} \text{less}
\]
Some thoughts about **Composition**

- Our `testrules.regex` need an input they can work with.
- Therefore they need to be at the second position of the composing process.

\[
\text{LEXICON} \rightarrow *pityless \rightarrow \text{RULES} \rightarrow pitiless
\]

- For the `LEXICON` to be dealt with first by the *composition operator*, it must be on top of the stack.
The Interface — Composing our Networks

Some thoughts about **Composition**

- Our `testrules.regex` need an input they can work with
- Therefore they need to be at the second position of the composing process

\[
\text{LEXICON} \rightarrow \ast \textit{pityless} \rightarrow \text{RULES} \rightarrow \textit{pitiless}
\]

- For the **LEXICON** to be dealt with first by the *composition operator*, it must be on top of the stack
- We therefore need to adjust our **SCRIPT**
The Script — Last Adjustments

First, we add

```
clear
read lexc < testlex.txt
eliminate flag LIQUID
eliminate flag COUNT
read regex < testrules.regex
turn stack
compose net
```
First, we add

- turn stack to our \textit{Script}.
First, we add

- turn stack to our **Script**.

We compose the two networks and add
First, we add

- `turn stack` to our `SCRIPT`.

We compose the two networks and add

- `compose net` which gives us a final `SCRIPT`:
The Script — Last Adjustments

First, we add

- turn stack to our SCRIPT.
  We compose the two networks and add
- compose net which gives us a final SCRIPT:

```
clear
read lexc < testlex.txt
eliminate flag LIQUID
eliminate flag COUNT
read regex < testrules.regex
turn stack
compose net
```
The Interface — Final Output

```
xfst[0]: source script.xfst
Opening file script.xfst...
Reading from 'testlex.txt'
Root...3, Noun...2, SgPl...2, Adj...1
Building lexicon...Minimizing...Done!
1.7 Kb. 19 states, 22 arcs, 9 paths.
Closing 'testlex.txt'
1.7 Kb. 18 states, 21 arcs, 8 paths.
1.6 Kb. 18 states, 22 arcs, 6 paths.
Opening file testrules.regex...
1.7 Kb. 9 states, 38 arcs, Circular.
Closing file testrules.regex...
1.7 Kb. 18 states, 22 arcs, 6 paths.
Closing file script.xfst...
xfst[1]: print lower-words
pity
pitable
milk
cars
car
carless
```

```
xfst[1]: up pityless
pity+A
```

```
xfst[1]: []
```
Theory of Finite State Morphology

- some facts — the book & the software
- some basic knowledge — finite state morphology
- building networks with xfst
  - The Lexicon
  - Regular Expressions
  - The Interface

possible applications

Practical application of Finite State Morphology
Possibilities of Finite-State-Morphology

Just to give you an overview on how far the power of Finite State Morphology reaches:
Possibilities of Finite-State-Morphology

Just to give you an overview on how far the power of Finite State Morphology reaches:

- Prefixes, suffixes and stem alternations
Possibilities of Finite-State-Morphology

Just to give you an overview on how far the power of Finite State Morphology reaches:

- Prefixes, suffixes and stem alternations
- Restricted reduplication (e.g. Tagalog: *kukuha* — “take”)
Possibilities of Finite-State-Morphology

Just to give you an overview on how far the power of Finite State Morphology reaches:

- Prefixes, suffixes and stem alternations
- Restricted reduplication (e.g. Tagalog: *kukuha* — “take”)
- Full stem reduplication (e.g. in Malay: *buku* — “book”; *buku-buku* — “books”)
Possibilities of Finite-State-Morphology

Just to give you an overview on how far the power of Finite State Morphology reaches:

- Prefixes, suffixes and stem alternations
- Restricted reduplication (e.g. Tagalog: *kukuha* — “take”)
- Full stem reduplication (e.g. in Malay: *buku* — “book”; *buku-buku* — “books”)
- Semitic stem interdigitation (e.g. Arabic)
Thank You for Listening!
Thank You for Listening!

Now turning to the practical part of the tutorial...
Login name: fast
Password: fast
Log on to: (this computer)

Please do not forget to constantly save EVERYTHING you do
in case the light goes...