Anatomy of ye olde garden path sentence
Anatomy of *ye olde garden path sentence*

- Classic example of incrementality in comprehension

*The horse raced past the barn fell.*
Anatomy of ye olde garden path sentence

• Classic example of incrementality in comprehension

```
"Main Verb"
```

```
The horse raced past the barn fell.
```

S

NP

VP
Anatomy of ye olde garden path sentence

• Classic example of incrementality in comprehension

  “Main Verb”

  The horse raced past the barn fell.
Anatomy of ye olde garden path sentence

- Classic example of incrementality in comprehension

```
NP          VP
  "Main Verb"
    S  "Reduced Relative"

The horse raced past the barn fell.
```
Anatomy of ye olde garden path sentence

• Classic example of incrementality in comprehension

"Main Verb"  S  S  "Reduced Relative"
NP  NP  VP  VP

The horse raced past the barn fell.
Anatomy of *ye olde garden path sentence*

- Classic example of incrementality in comprehension

```
"Main Verb"  S  "Reduced Relative"
NP  NP  VP  VP
```

The horse raced past the barn fell.

that was
Anatomy of ye olde garden path sentence

- Classic example of incrementality in comprehension

"Main Verb" S S "Reduced Relative"

NP NP VP VP

The horse raced past the barn fell.
Anatomy of *ye olde garden path sentence*

- Classic example of incrementality in comprehension

```
\text{The horse raced past the barn fell.}
```

(The evidence examined by the lawyer was unreliable.)
Anatomy of ye olde garden path sentence

• Classic example of incrementality in comprehension

The horse raced past the barn fell.

NP
S
NP
VP
S
“Main Verb”
“Reduced Relative”
Anatomy of ye olde garden path sentence

• Classic example of incrementality in comprehension

The horse raced past the barn fell.

• People fail to understand it most of the time
Anatomy of ye olde garden path sentence

- Classic example of incrementality in comprehension
- People fail to understand it most of the time
- People are likely to misunderstand it—e.g.,
  - “What’s a barn fell?”
  - The horse that raced past the barn fell
  - The horse raced past the barn and fell
Garden-pathing and surprisal

When the dog scratched the vet and his new assistant removed the muzzle.

(Frazier & Rayner, 1982)
Garden-pathing and surprisal

- Here's another type of local syntactic ambiguity

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- Here's another type of local syntactic ambiguity

  When the dog scratched the vet and his new assistant removed the muzzle.

- Compare with:

  When the dog scratched, the vet and his new assistant removed the muzzle.

  When the dog scratched its owner the vet and his new assistant removed the muzzle.

(Frazier & Rayner, 1982)
Garden-pathing and surprisal

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(Frazier & Rayner, 1982)
Garden-pathing and surprisal

- Here's another type of local syntactic ambiguity

  When the dog scratched the vet and his new assistant removed the muzzle.

  difficulty here
  (68ms/char)

- Compare with:

  When the dog scratched, the vet and his new assistant removed the muzzle.

  easier
  (50ms/char)

  When the dog scratched its owner the vet and his new assistant removed the muzzle.

  (Frazier & Rayner, 1982)
A small PCFG for this sentence type

S → SBAR S 0.3  Conj → and 1  Adj → new 1
S → NP VP 0.7  Det → the 0.8  VP → V NP 0.5
SBAR → COMPL S 0.3  Det → its 0.1  VP → V 0.5
SBAR → COMPL S COMMA 0.7  Det → his 0.1  V → scratched 0.25
COMPL → When 1  N → dog 0.2  V → removed 0.25
NP → Det N 0.6  N → vet 0.2  V → arrived 0.5
NP → Det Adj N 0.2  N → assistant 0.2  COMMA → , 1
NP → NP Conj NP 0.2  N → muzzle 0.2
NP → NP Conj NP 0.2  N → owner 0.2

(analysis in Levy, 2011)
A small PCFG for this sentence type

S → SBAR S 0.3
S → NP VP 0.7
SBAR → COMPL S 0.3
SBAR → COMPL S COMMA 0.7
COMPL → When 1
NP → Det N 0.6
NP → Det Adj N 0.2
NP → NP Conj NP 0.2

Conj → and 1
Adj → new 1
Det → the 0.8
VP → V NP 0.5
Det → its 0.1
VP → V 0.5
Det → his 0.1
V → scratched 0.25
N → dog 0.2
V → removed 0.25
N → vet 0.2
V → arrived 0.5
N → assistant 0.2
COMMA → , 1
N → muzzle 0.2
N → owner 0.2

(analysis in Levy, 2011)
Two incremental trees
Two incremental trees

- “Garden-path” analysis:

```
S
   SBAR
      COMPL
         When
         NP
         V
         Det N V NP Conj N
         the dog scratched and the vet
         NP
         Det Adj N
         his new assistant

S
   NP VP
      V
```
Two incremental trees

• “Garden-path” analysis:

S

SBAR

WHEN

NP

V

the dog scratched

S

NP

V

his new assistant

the vet
Two incremental trees

• “Garden-path” analysis:

\[ P(T|w_{1...10}) = 0.826 \]
Two incremental trees

• “Garden-path” analysis:

- \( P(T|w_{1...10}) = 0.826 \)

• Ultimately-correct analysis
Two incremental trees

• “Garden-path” analysis:

  $P(T_{10} | w_{1...10}) = 0.826$

• Ultimately-correct analysis:

  $P(T_{10} | w_{1...10}) = 0.174$
Two incremental trees

- “Garden-path” analysis:

- Ultimately-correct analysis

\[ P(T|W_{1...10}) = 0.826 \]

\[ P(T|W_{1...10}) = 0.174 \]
Two incremental trees

- “Garden-path” analysis:

- Ultimately-correct analysis

\[ P(T|w_{1...10}) = 0.826 \]

\[ P(T|w_{1...10}) = 0.174 \]
Two incremental trees

- "Garden-path" analysis:

```
When the dog scratched the vet and his new assistant
```

\[ P(T|w_{1:10}) = 0.826 \]

- Ultimately-correct analysis:

```
When the dog scratched the vet and his new assistant
```

\[ P(T|w_{1:10}) = 0.174 \]
**Two incremental trees**

- **“Garden-path” analysis:**
  
  Disambiguating word probability marginalizes over incremental trees:

  \[
  P(T|w_{1\ldots10}) = \sum_T P(\text{removed}|T) P(T|w_{1\ldots10})
  = 0.826 \times 0 + 0.174 \times 0.25
  \]

  \[
  P(T|w_{1\ldots10}) = 0.826
  \]

- **Ultimately-correct analysis**

  \[
  P(T|w_{1\ldots10}) = 0.174
  \]
Preceding context can disambiguate

- “its owner” takes up the object slot of scratched

<table>
<thead>
<tr>
<th>Condition</th>
<th>Surprisal at Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>NP absent</td>
<td>4.2</td>
</tr>
<tr>
<td>NP present</td>
<td>2</td>
</tr>
</tbody>
</table>
Sensitivity to verb argument structure

• A superficially similar example:

  When the dog arrived the vet and his new assistant removed the muzzle.

(Staub, 2007)
Sensitivity to verb argument structure

- A superficially similar example:

  When the dog arrived the vet and his new assistant removed the muzzle.

(Staub, 2007)
Sensitivity to verb argument structure

- A superficially similar example:

When the dog arrived the vet and his new assistant removed the muzzle.

But harder here! Easier here

(Staub, 2007)
Sensitivity to verb argument structure

• A superficially similar example:

When the dog arrived the vet and his new assistant removed the muzzle.

(c.f. When the dog scratched the vet and his new assistant removed the muzzle.)

(Staub, 2007)
<table>
<thead>
<tr>
<th>S → SBAR S</th>
<th>0.3</th>
<th>Conj → and</th>
<th>1</th>
<th>Adj → new</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>S → NP VP</td>
<td>0.7</td>
<td>Det → the</td>
<td>0.8</td>
<td>VP → V NP</td>
<td>0.5</td>
</tr>
<tr>
<td>SBAR → COMPL S</td>
<td>0.3</td>
<td>Det → its</td>
<td>0.1</td>
<td>VP → V</td>
<td>0.5</td>
</tr>
<tr>
<td>SBAR → COMPL S COMMA</td>
<td>0.7</td>
<td>Det → his</td>
<td>0.1</td>
<td>V → scratched</td>
<td>0.25</td>
</tr>
<tr>
<td>COMPL → When</td>
<td>1</td>
<td>N → dog</td>
<td>0.2</td>
<td>V → removed</td>
<td>0.25</td>
</tr>
<tr>
<td>NP → Det N</td>
<td>0.6</td>
<td>N → vet</td>
<td>0.2</td>
<td>V → arrived</td>
<td>0.5</td>
</tr>
<tr>
<td>NP → Det Adj N</td>
<td>0.2</td>
<td>N → assistant</td>
<td>0.2</td>
<td>COMMA → ,</td>
<td>1</td>
</tr>
<tr>
<td>NP → NP Conj NP</td>
<td>0.2</td>
<td>N → muzzle</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>N → owner</td>
<td>0.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
<table>
  <thead>
    <tr>
      <th>Phrase Type</th> <th>Production Rule</th> <th>Probability</th> <th>Word Type</th> <th>Word</th> <th>Probability</th>
    </tr>
  </thead>
  <tbody>
    <tr>
      <td>S</td> <td>→ SBAR S</td> <td>0.3</td> <td>Conj</td> <td>and</td> <td>1</td>
    </tr>
    <tr>
      <td>S</td> <td>→ NP VP</td> <td>0.7</td> <td>Det</td> <td>the</td> <td>0.8</td>
    </tr>
    <tr>
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    </tr>
    <tr>
      <td>SBAR</td> <td>→ COMPL S COMMA</td> <td>0.7</td> <td>Det</td> <td>his</td> <td>0.1</td>
    </tr>
    <tr>
      <td>COMPL</td> <td>→ When</td> <td>1</td> <td>N</td> <td>dog</td> <td>0.2</td>
    </tr>
    <tr>
      <td>NP</td> <td>→ Det N</td> <td>0.6</td> <td>N</td> <td>vet</td> <td>0.2</td>
    </tr>
    <tr>
      <td>NP</td> <td>→ Det Adj N</td> <td>0.2</td> <td>N</td> <td>assistant</td> <td>0.2</td>
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      <td>NP</td> <td>→ NP Conj NP</td> <td>0.2</td> <td>N</td> <td>muzzle</td> <td>0.2</td>
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    <tr>
      <td>NP</td> <td>→ NP Conj NP</td> <td>0.2</td> <td>N</td> <td>owner</td> <td>0.2</td>
    </tr>
    <tr>
      <td>Adj</td> <td>→ new</td> <td>1</td>
    </tr>
    <tr>
      <td>VP</td> <td>→ V NP</td> <td>0.5</td>
    </tr>
    <tr>
      <td>VP</td> <td>→ V</td> <td>0.5</td>
    </tr>
    <tr>
      <td>V</td> <td>→ scratched</td> <td>0.25</td>
    </tr>
    <tr>
      <td>V</td> <td>→ removed</td> <td>0.25</td>
    </tr>
    <tr>
      <td>COMMA</td> <td>→ ,</td> <td>1</td>
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</table>
Modeling argument-structure sensitivity

- The “context-free” assumption doesn’t preclude relaxing probabilistic locality:

(Johnson, 1999; Klein & Manning, 2003)
Modeling argument-structure sensitivity

- The “context-free” assumption doesn’t preclude relaxing probabilistic locality:

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### Modeling argument-structure sensitivity

<table>
<thead>
<tr>
<th>Production</th>
<th>Probability</th>
<th>Production</th>
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<td>N → assistant</td>
<td>0.2</td>
</tr>
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<td>NP → NP Conj NP</td>
<td>0.2</td>
<td>N → muzzle</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N → owner</td>
<td>0.2</td>
</tr>
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</table>

- The “context-free” assumption doesn’t preclude relaxing probabilistic locality:

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<thead>
<tr>
<th>Production</th>
<th>Probability</th>
<th>Replaced by</th>
</tr>
</thead>
<tbody>
<tr>
<td>VP → V NP</td>
<td>0.5</td>
<td>VP → Vtrans NP</td>
</tr>
<tr>
<td>VP → V</td>
<td>0.5</td>
<td>VP → Vtrans</td>
</tr>
<tr>
<td>V → scratched</td>
<td>0.25</td>
<td>VP → Vintrans</td>
</tr>
<tr>
<td>V → removed</td>
<td>0.25</td>
<td>VP → Vintrans NP</td>
</tr>
<tr>
<td>V → arrived</td>
<td>0.5</td>
<td>Vtrans → scratched</td>
</tr>
<tr>
<td></td>
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(Johnson, 1999; Klein & Manning, 2003)
When the dog arrived the vet and his new assistant removed the muzzle.

When the dog scratched the vet and his new assistant removed the muzzle.

<table>
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<tr>
<th>Condition</th>
<th>Ambiguity onset</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intransitive (arrived)</td>
<td>2.11</td>
<td>3.20</td>
</tr>
<tr>
<td>Transitive (scratched)</td>
<td>0.44</td>
<td>8.04</td>
</tr>
</tbody>
</table>
Move to broad coverage

- Instead of the pedagogical grammar, a “broad-coverage” grammar from the parsed Brown corpus (11,984 rules)

- Relative-frequency estimation of rule probabilities (“vanilla” PCFG)