"Garden path" sentences are those that trick you into thinking that they will mean one thing, but then as you read more of the sentence, that meaning is shown to be false!

For instance: "The horse raced past the barn fell"!

why, that sentence is senseless!

Aha, my friend, so it would seem! But it actually refers to a horse, which at some point in the past was raced past a barn, and now that same horse has fallen over!

That sentence is stupid!

what I'm SAYING is that nobody would ever say that. They'd say, "The horse that I raced past the barn has now fallen over"!

Sure man, all the time!

well, they could, but they could ALSO say my sentence!

Farmers call them nature's dominoes!

what are you saying?

only if they were incurably insane! Do horses even fall over?

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Sentence Processing

The Processing of Sentences

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Why syntax?

• Syntax: The system of rules or principles that governs how words in sentences relate to one another.

• Syntactic parsing: The mental process of identifying and using cues to discover how words in sentences relate to one another.

• Because syntax contributes to meaning.
  – E.g., phrase packaging

"Dr. Phil discussed sex with Rush Limbaugh."
Dr. Phil discussed sex with Rush Limbaugh.

Dr. Phil had a discussion with Rush Limbaugh about sex.

vs.

Dr. Phil had sex with Rush Limbaugh and talked about it afterwards.
• **Phrase Structure Trees**

• *E.g., A sentence is a noun phrase plus a verb phrase.*

\[
S \rightarrow NP + VP
\]
• *Phrase Structure Trees: Nodes and branches.*

```
S
/ | \
NP VP
```

Dr. Phil…
...(discussed sex) (with Rush Limbaugh).
Dr. Phil discussed sex (with Rush Limbaugh.)

Dr. Phil discussed (sex with Rush Limbaugh.)
• Dr. Phil discussed sex with Rush Limbaugh is *globally ambiguous*.

• Many sentences are *temporarily ambiguous*.

\[ \text{While Susan was dressing the baby was playing on the floor.} \]

*vs.*

\[ \text{While Susan was dressing } \textbf{herself} \text{ the baby was playing on the floor.} \]

(Frazier & Rayner, 1982)
Increased processing load in temporarily ambiguous sentences often occurs at the **disambiguating** point.

*While Susan was dressing the baby* was playing on the floor.

**Evidence for:**

- Immediacy
- Incremental Interpretation
- Syntactic Structure Errors (*garden-pathing*)
Why are garden-path sentences hard to understand?

- Theories of *parsing* describe the mental processes that people use to build syntactic structure representations.

- Those theories must explain why some sentences are harder to process than others.
• Models of Parsing:
  – Two-stage models (e.g., Frazier, 1979)
  – Constraint-based models (e.g., MacDonald et al., 1994)
  – Construal (Frazier & Clifton, 1996)
  – Race-based parsing (e.g., Traxler, Pickering, & Clifton, 1998)
  – Good-enough parsing (Ferreira, 2003)
Models of Parsing

• Two Stage Models: E.g., Garden-Path Model
  – Stage 1: identify syntactic categories and build initial structure
  – Stage 2: assess outcome against context, semantic plausibility, real-world knowledge
  – Revise if necessary
• Garden-Path Model Assumptions

  – Incrementality: word-by-word parsing.
  – Serial processing: one structure at a time.
  – Simplicity: no unnecessary structure; build the least complex representation.
• Garden-Path Model: Heuristics
  – *Late Closure*: Do not postulate unnecessary structure. If possible, continue to work on the same phrase or clause as long as possible.
  – *Minimal attachment*: When more than one structure is possible, build the structure with the fewest nodes.
• Garden Path Model: Late Closure Heuristic

While Mary was dressing the baby…

[While Mary was dressing the baby]…

vs.

[While Mary was dressing] [the baby…]
Garden-Path Model

- *Minimal Attachment* heuristic

```
S ————> [NP] Dr. Phil
       |       |       |       |
       V     |       |       |
       NP   V       |       |
       PP   NP     PP

S ————> [NP] Dr. Phil
       |       |       |       |
       V     |       |       |
       NP   V       |       |
       PP   NP     PP
```

Dr. Phil (discussed sex) (with Rush Limbaugh.)

Dr. Phil discussed (sex with Rush Limbaugh.)
• **Garden-Path Model:**
  – Predicts difficulty at *disambiguating point*.
    • *IF* actual structure is more complex than initial structure.

  – E.g., *The burglar blew up the safe with the rusty lock.*
  more difficult than

  *The burglar blew up the safe with the dynamite.*
The burglar blew up the safe with the rusty lock.

Initial structure – implausible interpretation:

```
S
  NP  VP
    V  NP  PP
      ...blew up  the safe  with the rusty lock.
```
The burglar blew up the safe with the dynamite.

Initial structure – plausible interpretation:

```
S
   /\  \\
  NP VP
     /   \
    V   PP
       /   \   \
     NP the safe dynamite.
```

…the burglar…blew up the safe with the dynamite.
The burglar blew up the safe with the rusty lock.

Final structure – plausible interpretation:

```
S
  └── NP
      └── V
          └── VP
              └── NP
                  └── N
                      └── PP
                          └── the safe
                              └── with the rusty lock.
                              └── blew up
```
Constraint-Based Models

• Constraint-Based Assumptions:
  – Sentences are represented as patterns of activation in a neural network.
  – Parsers build or activate all licensed structures simultaneously (parallel processing).
  – Structures compete for activation.
  – Interpretations are ranked.
    • Most likely structure gets highest activation.
  – The parser uses many sources of information to compute likelihood.
Constraint-Based Parsers

• Story Context Effects:
  – e.g., The burglar blew up the safe with the rusty lock.
  – Why is this difficult?
    • Garden-Path Model: complexity.
    • Constraint-based Model: pre-supposition violations.
Constraint-Based Models

• Story Context Effects:
  – The burglar was planning his next job. He knew that the warehouse had two safes. Although one was brand new from the factory, the other had been sitting out in the rain for ten years.

  The burglar blew up the safe with the rusty lock.

This sentence is easy to process in this story context.

(Altmann & Steedman, 1988; Altmann et al., 1992)
Constraint-Based Models

• Subcategory frequency effects:

  – Verbs sometimes need partners (e.g., arguments).

    *John slept.*

    *John took.*
Constraint-Based Models

• Subcategory Frequency Effects:
  – Sometimes, partners are optional.

  *John read.*
  *John read the story.*
  *John read the story to the little girl.*
Constraint Based Models

- Subcategory Frequency Effects:
  - saw

  - The student saw the answer...

    a. ...to the question. (likely) (direct-object)

    b. ...was in the back of the book. (less likely) (sentence complement)
The student saw the answer...

The student saw the answer was in the back of the book.
Constraint Based Models

• Subcategory Frequency Effects

saw vs. realized

– John saw x… 90% object, 10% complement

– John realized x… 10% object, 90% complement

Does the parser pay attention to subcategory frequency?

If so, John saw + complement should be harder than John realized + complement.
Figure 2. Word-by-word self-paced reading times (in ms). (NP = noun phrase; S = sentence.)
Constraint Based Models

• The *grain size problem*: What statistics do people keep track of?

  – N V N = Subject, verb, object frequently.
  – N *realized N* = Subject, verb, complement frequently.
  – N *realized a profit/his goals/her ambition* = Subject, verb, object.

One solution: count them all, use fancy math to maximize accuracy of predictions.
Constraint Based Models

• Semantic Effects:
  
  – Some entities are good agents (do-ers); some are not.

  – This can affect structural predictions.

• The defendant examined...
  ...
  ...the evidence.
  ...by the lawyer...
Constraint Based Models

Semantic Effects

*Defendant* examined

*examined* can be a main verb: *The defendant examined the evidence.*

*examined* can be part of a modifying expression: Which defendant?

*The defendant (who was) examined by the lawyer...*

*defendant* is a good agent.
Constraint Based Models

Semantic Effects

*The evidence* examined...

*by the lawyer*... (likely)

*the glove*... (highly unlikely)

If the parser pays attention to semantics:

*The defendant* examined by the lawyer...

should be harder than

*The evidence* examined by the lawyer...
The defendant examined...
**Fig. 3.** Mean first pass reading times in ms (Experiment 2).
Constraint Based Models

• Visual Context Effects
  – Put the apple on the towel…Good job.
  – Put the apple on the towel…in the box. Good job.

on the towel is ambiguous between a goal (of put) and a modifier (of apple).
Visual Context Effects:

Visual context can supply *referential support* for the modifier interpretation.

If the parser pays attention to visual context, *Put the apple on the towel in the box* should be easier in a two-apple context than in a one-apple context.
“Put the apple on the towel in the box.”

“Put the apple that’s on the towel in the box.”

Fig. 1. Typical sequence of eye movements in the one-referent context for the ambiguous and unambiguous instructions. Letters show when in the instruction each eye movement occurred, as determined by the mean latency for that type of eye movement (A’ and B’ correspond to the unambiguous instruction).

“Put the apple on the towel in the box.”

“Put the apple that’s on the towel in the box.”

Fig. 2. Typical sequence of eye movements in the two-referent context. Note that the sequence and the timing of eye movements, relative to the nouns in the speech stream, did not differ for the ambiguous and unambiguous instructions.

Tanenhaus et al., 1995, Science
Constraint Based Accounts

• The *Argument Structure Hypothesis*
  – Verbs have *argument structures*.

*Rained* has 0 arguments: *It rained*.

*Melted* has 1: *The ice cream melted.*

*Bet* has four:  
1. *Dr. Phil* bet  
2. *Rush Limbaugh*  
3. *a sandwich*  
4. *that Big Brown would win the Kentucky Derby*. 
• Verbs can also have *adjuncts*: semantically optional, frequently omitted partners.

• E.g., *in his fifties* in

• *The saleswoman interested the man in his fifties.*
Constraint Based Accounts

- Syntactic structures that implement argument structures are stored in long-term memory (MacDonald et al., 1994).

- This raises the *leg-shaving problem*.
Constraint Based Accounts

- E.g., *was reading*...
Constraint Based Models

- But also…

...was reading the book to the girl at the park next to the fire station that was built by the pilgrims...
Constraint Based Models

• Possible solution: Store only argument-related structural information.
  – If so: between 1 and 5 structures are stored for each verb.
  – And other syntactic structures are generated “on the fly.”

  – If so, people should respond differently to arguments than adjuncts.
Constraint Based Models

- Evidence for Argument Structure Hypothesis:
  - Arguments are easier to process than adjuncts
    (Clifton et al., 1999; Speer & Clifton, 1998; Britt, 1994; Schutze & Gibson, 1999).
  - Ambiguous constituents are interpreted as arguments. (Boland & Blodgett, 2006)
  - Comprehenders supply “missing” arguments:
    The ship was sunk to collect the insurance.
    But *The ship sank to collect the insurance.
    (Mauner et al., 1995; Koenig, 2003)
Constraint Based Models

• Potential Limitations:
  – The parser may not always favor likely structures over simple ones. (Clifton et al., 1997; Pickering et al., 2000)
  – When context supports the complex structure, the simple one should be harder to process.
    • Little or no evidence supports this prediction. (Binder et al., 2001; but see Sedivy, 2002, Experiment 4)
Other Parsing Hypotheses

• Construal:
  – *Primary (argument)* relations are treated as described in the *Garden-Path model*.
  – *Non-primary (adjunct)* relations are subject to *construal*.
    • For non-primary relations, multiple structures are built in parallel.
    • Incoming words are *affiliated* with preceding context.
    • All available information is used to evaluate the quality of the different structures.
Other Parsing Hypotheses

• Construal
  – Applies to *relative clause attachment ambiguities*

*The daughter of the colonel who had a black *dress* ...*
*The daughter of the colonel who had a black *mustache* ...*

Late closure favors attachment to the second noun.
So, *mustache* should be easier to process than *dress*.

But, as predicted by *construal*, both are equally easy.

(Traxler et al., 1998; van Gompel et al., 2001)
Other Parsing Hypotheses

• Race Based Parsing
  – The parser builds multiple structures in parallel.
  – Structures do not inhibit one another – they race.
  – The first structure to rise above an activation threshold is selected and interpreted.
  – If the “winner” produces a bad interpretation, an alternative structure is evaluated.
Other Parsing Hypotheses

• Race Based Parsing vs. Competition & Mutual Inhibition:
  – Competition predicts more difficulty when more structures are possible.
  – Race does not.
  – E.g.,

  *The son of the colonel with the black mustache... vs. The daughter of the colonel with the black mustache...*

  They are equally hard to process. (Traxler et al., 1998; see also van Gompel et al., 2001)
Other Parsing Hypotheses

• Good Enough Parsing
  – Parsing may not always be necessary.
  – Especially when it is redundant with lexical information.
    • E.g., *mouse, cheese, eat*
  – GEP Predicts parsing errors when lexical information contradicts structural information.
    • *The mouse was eaten by the cheese.*
    • *While the hunter was stalking the deer in the zoo drank from the puddle.*
Long Distance Dependencies

- *Local vs. long-distance* dependencies:
  - 
  
  - The girl chased the boy. Vs. It was the boy whom the the girl chased.
  
Long Distance Dependencies

• Evidence for Gap-Filling
  – *Cross-modal priming*  (Nicol & Swinney, 1989)

  • RT to Associated primes faster at gap site than before.

  That’s the boy that the people at the party [pre-gap test site] liked [GAP test site]...

  – RT @ pre-gap site > RT @ gap site
Long Distance Dependencies

• Evidence for a *gap-free* account:

  *That’s the pistol in which the killer shot the hapless man [GAP SITE] yesterday.*

When does the sentence stop making sense?

  GAP hypothesis: at the gap site.
  
  gap-free hypothesis: at the verb *shot*.

Eye-tracking data: sentence becomes difficult at the verb *shot*, well before the gap site.

Working Memory and Parsing

• DLT (Gibson): Processing cost increases with distance between a filler and its partner.
  – The parser predicts how many categories it needs to complete a phrase.
  – Predictions load working memory.
  – Sentences with long-distance dependencies involve more predictions than local dependencies.

  *The boy chased*... direct-object predicted and located quickly.

  *That’s the boy*... verb predicted; parser has to wait.
Working Memory and Parsing

• DLT
  – Explains why *subject relatives* are easier than *object relatives*.
    • Subject relative: The lawyer that phoned the banker filed a suit.
    • Object relative: The lawyer that the banker phoned filed a suit.

(Wanner & Maratsos, 1978; Mak et al., 2002; Traxler et al., 2002; Weckerly & Kutas, 1999)
Working Memory and Parsing

• Semantic Information: *Indexical* Pronouns
  
The lawyer that the banker phoned filed a suit.

Is harder than:

The lawyer that *you* phoned filed a suit.

Because the indexical pronoun *you* is easy to keep separate from *lawyer*; but *banker* and *lawyer* are confusable.

(Gordon et al., 2001, 2006)
Semantic Information and Relative Clauses: Animacy

Object relative: The movie that the director watched won a prize.

Is easier to process than:

Object relative: The director that the movie pleased won a prize.

Because semantic information points toward the correct interpretation.

(Traxler et al., 2002, 2005)
Working Memory and Parsing

• Distance, Confusability, and Animacy effects:
  – Suggest a multi-factor model.
  – Load depends on:
    • Structural (distance) factors: long-distance dependencies harder than local dependencies.
    • Memory management factors: confusable entities are harder to manage than distinct entities.
    • Semantic-Structural interactions: syntax dictates semantic roles; some entities are better role players than others.
Working Memory and Parsing II: Individual Differences

• Old Data:
  – Working memory span predicts the size of syntactic complexity effects (e.g., King & Just, 1991; Fedorenko et al., 2006, 2007).

Fig. 6. Mean reading time per word for successive areas of the sentence, comprehending subjects only. (As in Fig. 3, parenthesized words are not included in the plotted points.) As before, “H” and “L” are used to plot reading times for High and Low span subjects, respectively.
Working Memory and Parsing II: Individual Differences

• **BUT:**
  – Some individuals with 0 (zero) working memory can parse complex sentences (Caplan & Waters, 1995; Waters & Caplan, 1992, 1996).
  – Individual working memory capacity does not predict the size of syntactic complexity effects.

• **AND:**
  – Some theories view *working memory capacity* as entirely fictitious.
    • *WMC effects are really practice/automaticity effects.* (MacDonald & Christiansen, 2002)
Review

• Syntax mediates between word meanings and sentence-meanings.

• Theories of syntactic parsing try to explain why some sentences are harder to understand than others.

• Parsing theories differ as to how many structures get built at one time and what evidence is used during structure-building processes.

• Processing load is a complex function of sentence and individual characteristics.