Chapter 4 🧩 Sentence Processing I

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Chapter 4: Sentence Processing I

📖 Required Reading

- **Traxler (2nd ed.), Chapter 4** — *Sentence Processing*.
  Link to Chapter 4

1. Introduction

1.1 Core Goal of Sentence Processing

Big question:
How do listeners and readers **turn a linear string of words into a hierarchical, meaningful structure** that recovers the speaker's intended message?

To do this, comprehenders must track **relational information**:

- which words are **subjects / objects**,
- which ones are **modifiers**,
- and how they function as **arguments** within phrases and clauses.

Language scientists distinguish two related areas:

- **Syntax**
  - Describes the **formal rules and cues** that signal word relations
  - e.g. **word order**, **prepositions**, **inflections**
- **Syntactic Parsing**
  - Studies **how comprehenders use these cues in real time**
  - i.e. how we build mental representations of sentence structure *as we go*

1.2 Why Word Organization Matters: Ambiguity and Meaning

A central challenge for sentence processing is **structural ambiguity**:

- The **same words** can be grouped into **different phrase structures**,
- which leads to **different meanings**.

This is not a flaw in language. It reflects **efficiency**:

- Speakers aim for **fluency**, not full explicitness.
- Listeners rely on **context and cues** to resolve the ambiguity.

Example (Pinker, 1994; Bever, 1970)

(1) Dr. Phil discussed sex with Rush Limbaugh

This sentence has (at least) two readings, each with a different phrase structure.

Interpretation 1 — Discussion Between Two People (Non-slanderous)

- **Phrase grouping:**
  - `[Dr. Phil] [discussed sex] [with Rush Limbaugh]`
- **Structure:**
  - The PP *with Rush Limbaugh* modifies the **verb** *discussed* → indicates the **other participant** in the discussion.
- **Fits a context like:**
  - You: *"What did Dr. Phil and Rush Limbaugh talk about?"*
  - Me: *"Dr. Phil discussed sex with Rush Limbaugh."*
  - → They **talked about** sex together.

Interpretation 2 — Sexual Relationship (Slanderous)

- **Phrase grouping:**
  - `[Dr. Phil] [[discussed] [sex with Rush Limbaugh]]`
- **Structure:**
  - The PP *with Rush Limbaugh* modifies the **noun** *sex* → specifies the **partner** in the sexual activity.
- **Fits a context like:**
  - You: *"Who did Dr. Phil have sex with?"*
  - Me: *"Dr. Phil discussed sex with Rush Limbaugh."*
  - → He **had sex with** Rush Limbaugh and talked about it.

1.3 Key Evidence: Incremental Processing and Garden Path Sentences

Research suggests an **immediacy principle** (Foss & Hakes, 1982; Just & Carpenter, 1980):

- Comprehenders **interpret words as soon as they hear or read them**.
- They do **not wait** for the end of the sentence to decide on structure.
- This is **efficient but risky**.

Consequence:

- Early structural choices can turn out to be **wrong** when later input arrives.
- Such sentences are called **garden path sentences**:
  - Temporarily ambiguous
  - Lead the reader down a "wrong path"
  - Require **reanalysis** once disambiguating information appears

Prompt for students

How would you complete this sentence?

> While Susan was dressing the baby _____.

Classic Garden Path Example (Frazier & Rayner, 1982)

> **(7)** While Susan was dressing the baby played on the floor
> **(8)** While Susan was dressing herself the baby played on the floor *(unambiguous control)*

Step 1 · Initial Ambiguity

In (7), the sequence **While Susan was dressing the baby** is structurally ambiguous:

- **Initial parse**
  - The parser attaches **the baby** as the **direct object** of *dressing*:
    - "While Susan was dressing **the baby** …"
  - So **the baby** is treated as part of the **subordinate clause**.
- **Why this parse?**
  - The **immediacy principle**: the system assigns **the baby** an object role **right away**, rather than leaving it unassigned.

Step 2 · Disambiguation and Revision

Problem at *played*

- When readers reach **played**, they hit a conflict:
  - *played* is a **main verb** that needs a **subject**,
  - but **the baby** has already been used as the **object** of *dressing* in the initial parse.

This forces **reanalysis** (undoing the first structure):

- **Revised parse**
  - The parser closes the subordinate clause after *dressing*:
    - "While Susan was dressing [herself], …"
  - **the baby** is reassigned as the **subject** of *played*:
    - "… **the baby** played on the floor."

Step 3 · Processing Cost Evidence

Reading–time data show the cost of this reanalysis:

- **No slowdown at *the baby***
  - At this point, sentences (7) and (8) are read **equally fast** → the ambiguity is **not yet detected**.
- **Significant slowdown at *played***
  - For (7), readers show a **200–300 ms slowdown** at *played* compared to (8) (Frazier & Rayner, 1982; Traxler, 2002).

- This extra time reflects the **effort of revising** the initial parse.

In contrast, (8) has **no ambiguity**:

- **herself** immediately fills the **object** role of *dressing*,
- so **the baby** is straightforwardly analyzed as the **subject** of *played*,
- and **no reanalysis** is needed.

2. Models of Parsing: Two-stage Models

> **Key idea:** Two-stage models (e.g., Frazier's *Garden Path Theory*) propose that **syntactic structure is built first → meaning is applied later.**
> Parsing proceeds in **two independent steps**, with no early semantic influence.

2.1 Stage 1: Structural Analysis (Syntax-First)

Input (Stage 1 uses only syntax):

- word category information (N, V, PP, etc.)
- no semantics or real-world expectations
- e.g., *dressing = verb*, *the baby = NP*, but parser ignores the fact that people dress babies.

Process (Stage 1):

- parser builds **one** syntactic structure
- uses **fast, context-free heuristics**
- goal: **simplicity and speed**

Output (Stage 1):

- one phrase-structure tree
- all roles (subject/object/modifier) assigned purely by syntax

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2.2 Stage 2: Semantic Interpretation and Revision

> **Inputs to Stage 2:**
> • structure from Stage 1
> • word meanings
> • discourse context
> • world knowledge

Process (Stage 2):

- a "thematic interpreter" assigns roles (agent, patient, goal)
- checks for semantic or contextual coherence

If conflict arises (e.g., at *played* in garden-path sentences),
the system triggers **reanalysis** of the initial syntactic structure.

2.3 Core Heuristics of Garden Path Theory

> These heuristics guide **Stage 1**.
> They are intended to be **universal**, **simple**, and **efficient**.

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1. Late Closure

> *"Attach new material to the phrase currently being processed."*

- avoids creating new nodes (saves effort)
- **Example**:
  - *While Susan was dressing the baby…*
  - parser keeps *the baby* inside the subordinate clause
- leads to garden-path at *played*

Evidence:

- slow reading times at *played* in the ambiguous version (7)

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2. Minimal Attachment

> *"Choose the structure with the fewest nodes."*

- fewer nodes = less cognitive work

The "Safe" Sentences

Sentence	Preferred PP Attachment	Reason
(11) *safe with the rusty lock*	→ NP	semantics force NP modification
(12) *safe with the dynamite*	→ VP	simplest structure

- (12): correct on first pass → fast
- (11): wrong initial choice → revision cost

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3. Main Assertion Preference

> *"Attach new information to the sentence's main clause."*

- main clause carries core message

Examples

- (13): attach *to the store* to *delivered*

- (14): attach *to the store* to *baked* (even if odd)

Conflict with Late Closure:

- both heuristics apply but cancel out
- reading times same for (13) and (14)

2.4 Limitations of Two-stage Models

1. No early semantic influence

- but context often affects parsing *before* disambiguation points

2. Claims universality

- but cross-linguistic differences (e.g., Spanish vs. English RC attachment) show parsing preferences depend on **language-specific frequency**, not universal heuristics.

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3. Models of Parsing: Constraint-based Models

(MacDonald et al., 1994; Tanenhaus et al., 1995)

A **one-stage, parallel-processing system** in which syntactic, semantic, and contextual cues contribute **simultaneously**.

3.1 Core Principles

1. Parallel Activation

> Multiple syntactic structures are activated at the same time.
> Example: *Dr. Phil discussed sex with…* → both PP-to-verb and PP-to-noun parses activate.

2. Constraint Satisfaction

> Competing structures rise or fall in activation depending on how strongly they are supported by available cues.

3. No Syntax-First Bias

> All information sources (syntax, semantics, context) influence parsing **from the start**.

3.2 Key Constraints (Cues) and Evidence

The parser uses a wide set of cues in parallel.
Empirical support comes from reading times, eye-tracking, and cross-modal priming.

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1. Story Context (Referential Context)

Context creates **referential needs**—making certain structures more likely.

Altmann & Steedman (1988)

- (11) *The burglar blew up the safe with the rusty lock.*
- **Isolated:** Ambiguous; minimal attachment picks the wrong structure → slow at *rusty lock*.
- **With Story:** Introduce two safes (one rusty).
  - Readers now **prefer** the PP to modify *safe* → reading times become fast.
  - Context overrides minimal attachment.

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2. Verb Subcategory Frequency

Verbs have stable structural preferences (object vs. complement).

Garnsey et al. (1997)

- *saw*: 90% → direct object; 10% → sentence complement
- *realized*: 90% → sentence complement; 10% → direct object

Experiments

- (28) *The student saw the answer was...* → slowdown at *was*
- (32) *The student realized the answer was...* → no slowdown

Conclusion: The parser predicts structure using verb-specific frequency.

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3. Cross-Linguistic Frequency

Attachment preferences reflect **language-specific statistics**.

Cuetos & Mitchell (1988)

Language	Preferred RC Attachment
English, Italian	Second noun
Spanish, French	First noun

These align with corpus frequencies in each language.

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4. Semantic Constraints (Animacy)

Semantic properties guide early structure activation.

Trueswell et al. (1994)

- (35) *The defendant examined by the lawyer…* (animate)
  - Parser assumes "defendant examined someone" → wrong
  - Slow at *by the lawyer*
- (39) *The evidence examined by the lawyer…* (inanimate)
  - Only passive structure activates → no slowdown

  Inanimate nouns strongly bias passive interpretations.

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5. Prosodic Constraints

Prosody marks phrase boundaries in real time.

Carlson et al. (2001)

- (41) *Susie learned that Bill telephoned after John visited.*

Prosody 1: pause after *telephoned* → modifies *learned*
Prosody 2: pause after *Bill* → modifies *telephoned*

Kjelgaard & Speer (1999)

- "Cooperating" prosody → faster responses
- "Conflicting" prosody → slower responses

  Prosodic cues shift structure interpretation within ~200 ms.

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6. Visual Context Constraints

Visual information can resolve ambiguity **before** linguistic cues.

Tanenhaus et al. (1995)
Sentence: (46) *The girl placed the apple on the towel in the box.*

Visual Scene 1: One Apple

- One apple + an empty towel
- Listeners look at the empty towel → garden path later

Visual Scene 2: Two Apples

- One apple *on a towel*, one on a napkin
- Listeners look at the apple on the towel → no garden path

  Visual context directs parsing within 200 ms of "on the towel."

3.3 The Tuning Hypothesis

The parser's cue weights are **shaped by experience** (Mitchell et al., 1995).

- Frequent cues become **stronger predictors**.
- Infrequent cues have **lower weight**.

Example (English)

- Animate nouns are agents ~80% of the time → strong agent bias.

Cross-Linguistic Example

- Spanish: first-noun RC attachment common → stronger first-noun bias
- English: second-noun RC attachment common → stronger second-noun bias

  Parsing is continuously "tuned" to the language environment.

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4. Interim Summary

4.1 Model Comparison: Two-stage vs. Constraint-based

Aspect	Two-stage Models (Garden Path)	Constraint-based Models
Processing Stages	Two (syntax → semantics)	One (all cues interact)
Structure Activation	Serial (one structure)	Parallel (multiple structures)
Cues Used	Only syntax in Stage 1	All cues: context, frequency, semantics, prosody, vision
Cause of Garden Paths	Heuristic errors (late closure, minimal attachment)	Competition among structures with different activation levels
Cross-Linguistic Differences	Universal heuristics	Frequency-based tuning within each language

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4.2 The Constraint-based Framework (Figure 4.3)

Core idea:
All available cues feed into a **single, parallel system**.

Each cue (e.g., verb frequency, story context, prosody, visual information, animacy) contributes **activation** to possible syntactic structures.

The parser:

1. **activates** multiple structures,
2. **weighs** them using cue strengths,
3. **selects** the structure with the highest overall activation.

This framework explains:

- why ambiguity sometimes causes difficulty (weak cue support),
- why context or vision can eliminate garden paths,
- and why languages differ in parsing preferences.

4.3 Beyond Parsing: Prediction in Sentence Processing

> Constraint–based models naturally extend to **prediction**:
> comprehenders use cues to anticipate upcoming words and structures before they appear.

Altmann & Kamide (1999)

- Participants heard: *The boy will eat…*
- Scene: cake, ball, car, train
- **Eye movements:**
  - Listeners looked at the **cake** *before* hearing the word *cake*.
  - Verb semantics (*eat*) triggered prediction of an edible object.

What does the parser predict?

- **Phonological prediction**
  - Likely upcoming sound shape
  - e.g., *eat… c–* → anticipating /k/ for *cake*
- **Syntactic prediction**
  - Likely category
  - e.g., *eat* predicts a **noun phrase**
- **Semantic prediction**
  - Likely meaning
  - e.g., *eat* predicts a **food item** (Kuperberg, 2021)

> Prediction shows that sentence processing is not just reactive—
> it is **anticipatory**, **probabilistic**, and guided by experience.