Announcements

HW: Pick up HW1, be working on HW2

Midterm review next Tuesday (2/3/09)
  - bring questions

Midterm next Thursday in class (2/5/09)
  - open note, write on exam
  - 6 problems (like homework questions), 15 multiple choice

Example multiple choice question format:

“Seven is an odd number.”
(a) True - six is an odd number, too.
(b) True - five is an odd number, too.
(c) False - seven is an even number.
(d) False - six is an odd number.

Morphology: Affixes

Computational Problem: Identifying word affixes that signal meaning.

Affix = sound sequence smaller than an entire word that is attached to a word in order to indicate some additional meaning (also known as bound morphemes - small units of meaning that cannot stand on their own. Instead they must be attached to some other word.)

Affix examples: prefix (un- in unsolvable), suffix (-ed in kissed)

un- = not, un- + solvable = unsolvable = not solvable
  “This labyrinth is unsolvable!”

-ed = past tense, kiss + -ed = kissed = kiss (past tense)
  “Sarah almost kissed Jareth last night in the ballroom.”

Focusing in on past tense morphology

What do you have to change about the verb to signal the past tense in English? (There are both regular and irregular patterns.)

<table>
<thead>
<tr>
<th>Affixed Verb</th>
<th>Affixed Verb</th>
<th>Affixed Verb</th>
</tr>
</thead>
<tbody>
<tr>
<td>blink~blinked</td>
<td>confide~confid</td>
<td>drink~drank</td>
</tr>
<tr>
<td>rub~rubbed</td>
<td>hide~hid</td>
<td>think~thought</td>
</tr>
</tbody>
</table>

(blinked in “She blinked.”)

(not drank in “He drank.”)
Focusing in on past tense morphology

What do you have to change about the verb to signal the past tense in English? (There are both regular and irregular patterns.)

| Verb | Morphology | Verbs in [red] | Verbs in [aj]
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Blink→blinked</td>
<td>confide→confided</td>
<td>drink→drank</td>
<td>rub→rubbed</td>
</tr>
<tr>
<td>[ad]</td>
<td>[ad]</td>
<td>([ch] → &quot;ey&quot;)</td>
<td>([en])</td>
</tr>
<tr>
<td>[ad]</td>
<td>[ad]</td>
<td>([i] → [e])</td>
<td>([o])</td>
</tr>
</tbody>
</table>

Recap from last time

Several theories attempt to explain how children (and adults) represent knowledge of morphology in their minds. One example of morphology is the English past tense.

The “Words & Rules” theory claims that regular and irregular verbs are produced by two different processes, that are controlled by two different pieces of the brain. This theory can explain children’s developmental trajectory as well as adult neurological evidence.

The “Words, No Rules” theory claims that both regular and irregular verbs are processed in associative memory. However, this theory requires special input conditions in order to match children’s developmental trajectory. In addition, it does not seem able to account for some adult neurological evidence.

Stay tuned for the “Rules, No Words” theory…

Three ideas for how the mind represents past tense morphology knowledge

“Words & Rules”: regular patterns are produced via a rule-like combinatorial process while irregular patterns are retrieved from associative memory.

“Words, No Rules”: both regular and irregular patterns are retrieved from associative memory.

“Rules, No Words”: both regular and irregular patterns are produced via a rule-like combinatorial process.

“Rules, No Words”: a closer look at irregular verbs

Irregular verbs tend to have “neighborhoods”, where certain verbs seem to follow the same patterns.

Pattern: no change to root form
- cut→cut, hurt→hurt, fit→fit, hit→hit, ...
- drink→drank, shrink→shrank, sink→sank, sing→sang, ring→rang, ...
- fly→flew, know→knew, throw→threw, draw→drew, …
Another way to think about irregular past tense patterns is that there are rules for irregular past tense forms (instead of these forms being memorized individually and retrieved from associative memory).

Irregular Rule: no change to root form
- cut~cut, hurt~hurt, fit~fit, hit~hit, ...

Irregular Rule: in [ŋ] --> an [ɛŋ]
- drink~drank, shrink~shrank, sink~sank, sing~sang, ring~rang, ...

Irregular Rule: final vowel sound --> oo [u]
- fly~flew, know~knew, throw~threw, draw~drew, ...

This means that there are two kinds of rules: irregular rules (which generally apply to a specific subset of verbs) and regular rules (which apply to all the rest of the verbs not included in the irregular rules).

Irregular Rule: no change to root form
- cut~cut, hurt~hurt, fit~fit, hit~hit, ...

Irregular Rule: in [ŋ] --> an [ɛŋ]
- drink~drank, shrink~shrank, sink~sank, sing~sang, ring~rang, ...

Irregular Rule: final vowel sound --> oo [u]
- fly~flew, know~knew, throw~threw, draw~drew, ...

Regular past tense rule: +ed [d], [t], [´d]
- Applies to all the other verbs
- walk, blink, sigh, ...

More specific:
- applies to just these verbs
- fly, know, throw, draw,

More general:
- Applies to all the other verbs
- walk, blink, sigh, ...

What’s the difference between retrieving irregular verb forms from associative memory and having an irregular rule that applies to those verbs?

If irregular verb forms are individually memorized and then retrieved from associative memory, then there is not much of a connection between verb forms that don’t have similar-sounding root forms. They are learned and retrieved separately, even if they follow a similar pattern to form the past tense.

Rule: Vowel --> “oo” [u]

If irregular verb forms are formed using an irregular rule, then even if the root forms don’t sound alike, they are all connected since the same process is used to form the irregular past tense form.
How do we know which representation is a more accurate reflection of the knowledge in children’s minds?

**Associative Memory only (no irregular rules):** Irregular past tense performance for any given verb is based largely on how frequently the child hears that verb’s past tense form.

What matters: frequency of that verb’s past tense form in the child’s input.

“flew” performance: How often does the child hear “flew”? 

**Irregular Rules:** Irregular past tense performance for any given verb is based on how frequently the child hears that past tense form and how often the child hears any irregular verbs that follow the same past tense rule.

What matters: frequency of that verb's past tense form and frequency of past tense forms that follow the same rule (rule frequency).

“flew” performance: How often does the child hear any of these forms?

**Predictions of each theory:**

**Associative Memory only (no irregular rules):** what matters is the frequency of that verb’s past tense form in the child’s input

Prediction: If children encounter two verbs’ past tense forms equally often, they should perform the same on each verb

**Irregular Rules:** what matters is the frequency of that verb’s past tense form and the frequency of past tense forms that follow the same rule (rule frequency)

Prediction: If children encounter two verbs’ past tense forms equally often, they should perform better on the verb that follows an irregular rule that is often used (which we can gauge by measuring how frequently other verbs that also use that rule are encountered)

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Evidence from CHILDES database

Children encounter “hurt” and “cut” as often as “draw”, “blow”, “grow”, and “fly” [20 times in a given corpus of child-directed speech]

Results:

- Performance on “hurt” and “cut”: ~80% success at correct irregular form
- Performance on “draw”, “blow”, “grow”, and “fly”: ~35% success

Different performance for same frequency verbs!

Why?
Evidence from CHILDES database

Children encounter “hurt” and “cut” as often as “draw”, “blow”, “grow”, and “fly” [20 times in a given corpus of a child’s experience]

Results:

Performance on “hurt” and “cut”: ~80% success at correct irregular form
Other verbs with same rule: hit, quit, split, slit, bid, rid, forbid, spread, wed, let, set, upset, wet, shut, burst, cost, thrust

Performance on “draw”, “blow”, “grow”, and “fly”: ~35% success
Other verbs with same rule: know, throw, withdraw, slay

Evidence from Yang (2002):

Irregular Rules

Summary of evidence: Even when children encounter irregular past tense verb forms with equal frequency, they do not have similar performance when producing these verb forms. Children are more successful on verb forms that are produced by a rule that has a higher frequency (in this case, the No Change rule) than those that are produced by a rule that has a lower frequency (in this case, the Vowel --> “oo” rule).

Support for the existence of Irregular Rules.
Evidence from CHILDES database

How often children encounter certain verbs in a given corpus:
- "hurt": 20 times
- "cut": 20 times
- "caught": 36 times
- "threw": 31 times
- "knew": 58 times

Performance on "hurt" and "cut": ~80% success
Performance on "caught": ~96% success
Performance on "threw": ~49% success
Performance on "knew": ~49% success

Better performance for less frequent verbs.

Irregular Rules

Evidence from CHILDES database

How often children encounter certain verbs in a given corpus:
- "hurt": 20 times
- "cut": 20 times
- "caught": 36 times
- "threw": 31 times
- "knew": 58 times

Performance on "hurt" and "cut": ~80% success
Performance on "caught": ~96% success
Performance on "threw": ~49% success
Performance on "knew": ~49% success

Different performance for equally frequent verbs.

Explaining Yang (2002) evidence

Children’s performance can be explained by irregular rule frequency. Children do better on verbs that follow rules with a higher frequency - even if the individual verb form itself is less frequent.

-No Change rule: hurt~hurt, cut~cut
hit, quit, spit, sit, spit, bid, bid, forbid, spread, rend, let, set, upset, wet, shut, bid, hurt, cast, cost, thrust
many verbs = high rule frequency
rule frequency: > 2500, better performance

-Change to ‘ought’ rule: catch~caught
buy, bring, teach, think
fewer verbs, but some are frequent = higher rule frequency
rule frequency: > 600, better performance

-Vowel goes to ‘oo’ rule: throw~threw, know~knew
draw, blow, fly, withdraw, say
fewer verbs, and most are infrequent = lower rule frequency
rule frequency: < 100, poorer performance

Irregular Rules: Recap

Children’s performance on irregular past tense verb forms suggests that they produce irregular past tense verb forms with irregular rules. This is because the individual frequency of a past tense verb form only partially determines how well children perform on that verb. The frequency of the irregular rule used to produce that verb form also seems to influence children’s performance. So, even if an individual verb form does not appear very frequently itself (ex: cut, hurt), if it is produced by a rule that does get used frequently (ex: the No Change rule), children are likely to do well on that individual verb form (ex: performance around 80% use of correct past tense form).
Question: When do children figure out that they need a rule for certain groups of verbs?

Idea: The point of using rules for past tense forms would be that it’s easier in some sense -- as opposed to simply remembering each verb and its associated past tense individually.

If a particular transformation (rule) occurs a lot (like +ed), it’s said to be productive. Productive rules make sense to have because they’re used for a lot of different verbs.

Question: What determines if a rule is productive? That is, how does a child decide that a rule is used enough to be worth having?

Words To Rules?

Idea: The point of using rules for past tense forms would be that it’s easier in some sense -- as opposed to simply remembering each verb and its associated past tense individually.

look looked kiss kissed lurch lurched laugh laughed dance danced
harder easier

look look
kiss kiss
lurch lurched
laugh laughed
dance danced

verbs that follow the rule: ring ~ rang, sing ~ sang, ...

Verbs that don’t follow the rule: sting ~ sung, bring ~ brought, string ~ strung, cling ~ clung, ping ~ pinged, ding ~ dinged...
Important: a rule can be productive while still having exceptions. The big question is simply how many exceptions is too much?

**ed Rule:** [any verb] -> [any verb]+ed

Verbs that follow the rule: look~looked, kiss~kissed, laugh~laughed,…

How many?

Verbs that don’t follow the rule: sting~sung, bring~brought, drink~drank, ring~rang, keep~kept,…

How many?

Yang (2005): What matters is how long it takes to find the right past tense form.

There are two options when some verbs follow a rule and some items don’t.
1. Store all the exceptions to the rule, and then the rule. If the verb needed isn’t among the exceptions, apply the rule.
2. Just store all the verbs and their past tense forms individually. (Treat all the verbs as exceptions.)

Tolerance Principle: If it takes longer (on average) to find the right past tense form when both the exceptions and the rule are stored (option 1), just store all the verbs separately (option 2).

Note: Exceptions to rule are in order of frequency

Rule: *ing-*ang

- If word = sting then stung (freq 100)
- Else if word = swinging then swung (freq 80)
- Else if word = ding then dinged (freq 10)
- Else if word = cling then clung (freq 8)
- Else Apply *ing --> *ang

Note: Exceptions to rule are in order of frequency

Rule: *ing-*ang

- If word = sting then stung (freq 100) (Time 1) look here
- Else if word = swing then swung (freq 80) (Time 2) look here
- Else if word = ding then dinged (freq 10)
- Else if word = cling then clung (freq 8)
- Else Apply *ing --> *ang

swing? --> swung

Time units to find: 2
Productive Rules

Yang (2005): What matters is how long it takes to find the right past tense form.

Note: Exceptions to rule are in order of frequency

Rule: "ing-*ang"

If word = sting then stung (freq 100) (Time 1) look here
Else if word = swing then swung (freq 80) (Time 2) look here
Else if word = ding then dinged (freq 10) (Time 3) look here
Else if word = cling then clung (freq 8) (Time 4) look here
Else Apply "ing --> *ang" (Time 5) look here

ring? ---> rang

Time units to find: 5 + rule application

Tolerance Principle Prediction

Regular +ed rule can only be productive if it applies to the vast majority of verbs it could apply to (relatively few exceptions).

Regular rule:
Which verb forms should this rule apply to?
No restrictions on form: kiss, kick, cry, hug, ...
form = [any form]
Transformation: [any form] --> [any form] + ed

There are 150 irregular verbs, which are exceptions to the regular rule because they fit the [any form] context that the regular rule applies to.

Tolerance Principle Prediction

Regular +ed rule
Transformation: [any form] --> [any form] + ed

Verbs that obey this rule: all the regular verbs in English (suppose we let this be 10000, just for demonstration purposes).

Verbs that do not obey this rule: all irregular verbs (150)

Tolerance Principle: a precise mathematical formula that considers the total number of verbs the rule could potentially apply to (regular + irregular verbs) and how many it actually doesn’t apply to (irregular verbs).

If Exceptions < Potential/ ln(Potential), then it is faster to have a rule instead of storing all the verb forms individually.

Tolerance Principle Prediction

Regular +ed rule
Transformation: [any form] --> [any form] + ed

Verbs that obey this rule: all the regular verbs in English (suppose we let this be 10000, just for demonstration purposes).

Verbs that do not obey this rule: all irregular verbs (150)

Exceptions = 150
Potential = 10000 + 150 = 10150
Potential/ln(Potential) = 10150/ln(10150) = 10150/9.23
= 1100

Is 150 < 1100? Yes. Tolerance Principle states that it is faster to have a rule than to store each individual past tense form separately.
Tolerance Principle Prediction

How many regular verbs need to exist in order for it to be faster to have a rule when there are 150 exceptions?

Verbs that do not obey this rule: all irregular verbs (150)
Verbs that obey this rule: ???? (let’s call this x)

Exceptions = 150
Potential = x + 150

What is the threshold at which it’s better to have a rule with 150 exceptions?

\[ \text{Exceptions} = \text{Potential} \times \ln(\text{Potential}) \]

\[ 150 = (x + 150) \times \ln(x + 150) \]

\[ x \approx 890 \]

[Check: \((890 + 150) \times \ln(890 + 150) = 1040 \times \ln(1040) \approx 150\)]

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Tolerance Principle in Child Learning

1) Child identifies possible rule.
   Ex: (*ing --> *ang)

2) Child (unconsciously) checks current vocabulary with Tolerance Principle to see if it’s better to store a rule + exceptions, or just store everything individually.

3) Child repeats with each new word type encountered. (Productivity of rules can change, based on how many exceptions the child is aware of at any given time.)

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Productivity Predictions

Depending on the verbs they have encountered, children may believe certain rules are productive while other rules are not.

Prediction for English regular +ed rule: Children who have this rule should know many more regular verbs than irregular verbs, in order for it to be faster for them to have a rule. (This seems to be true - children who overregularize (and thus have the rule) seem to know many more regular verbs than irregular verbs.)
Summary: Storing Rules vs. Words

It makes sense from a processing standpoint for children to store rules if these rules are used a lot - that is, if they are productive rules. Otherwise, it will be easier to simply store individual words and their associated past tense forms.

One way children might decide if a rule should be stored is based on how many verbs follow the rule vs. how many verbs do not follow the rule. The important thing is to store the knowledge in such a way as to make it faster to find a given past tense form.

Evidence from children’s input and behavior suggests that children who know the regular past tense rule in English (and who may overregularize) do know more verbs that follow the regular rule (regular verbs) than verbs that do not follow the rule (irregular verbs).

Questions?