LING5702: Lecture Notes 10
Hierarchic Sequential Prediction

We've seen syntactic structural knowledge constrains trees, but how do we guess trees from words?

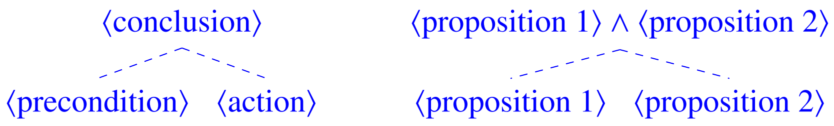
As an approximation, we base structural processing on domain-general complex event prediction.

We predict complex events in memory, using learned (generalized) rules of causation.

Contents

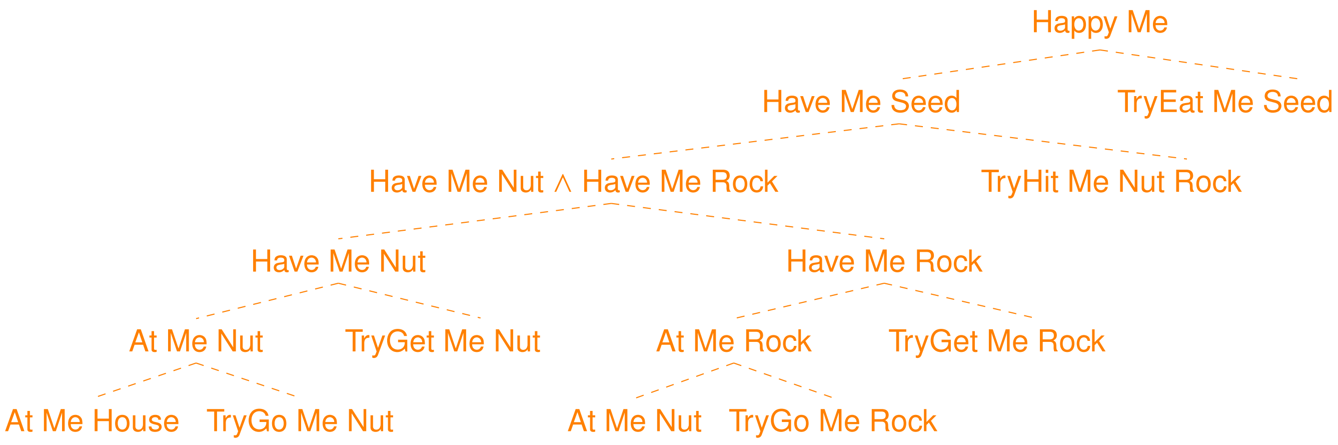
10.1 Complex events

We assume complex events are made of preconditions and actions, or conjoined propositions:



Events can contain hierarchies of subevents, especially complex plans (complex ideas).

Here's a complex event for breaking open a nut with a rock and eating the seed inside:



Sub-events are related to parent events by cued associations for 'cause' predications.

When similar (recognition) operations are nested inside other operations, a process is called **recursive**.

10.2 Event fragments

Humans and (some) animals can recognize and re-create complex hierarchic events.

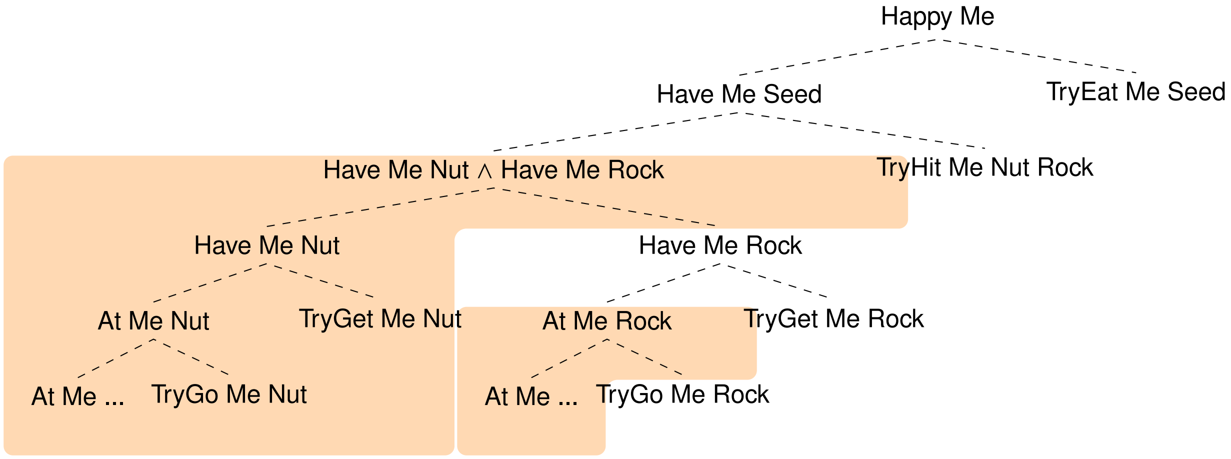
[Fuster, 1990, Botvinick, 2007]

Partial sequences of events can be grouped and stored as **event fragments** a/b, where:

- a is a **predicted outcome** 'apex' top-level event or sub-event,
- b is an **expected part** 'base' sub-event / observed event yet to come, which completes the outcome.

E.g. At Me Rock can be accounted as Have Me Rock / TryGet Me Rock.

Here's a set of event fragments recognized from observations in time order, up to TryGo Me Rock:



Near-complete sub-events can be chained together to save memory:

E.g. ... / Have Me Rock and At Me Rock form ... / TryGet Me Rock.

When a recent event fragment is completed, it can be added to an earlier event fragment.

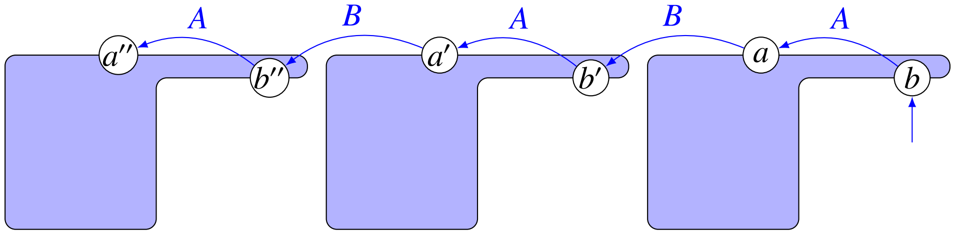
E.g. if At Me Rock is complete, it can satisfy Have Me Rock with TryGet Me Rock expected.

Uncertainty about events may be modeled using superposed activation vectors, described earlier.

10.3 Recognition Model [Johnson-Laird, 1983]

This model maintains a sequence of event fragments accessible from a most recent expectation b:

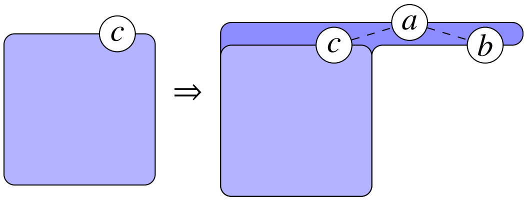
- Cued associations 'A' directly link individual expectations b to supported outcomes a.
- Cued associations 'B' directly link individual outcomes a to preceding expectations b.



E.g. a'/b' is ... / Have Me Rock, a/b is At Me Rock / TryGo Me Rock.

Crucially, this store can only be a few elements long before interference causes trouble.

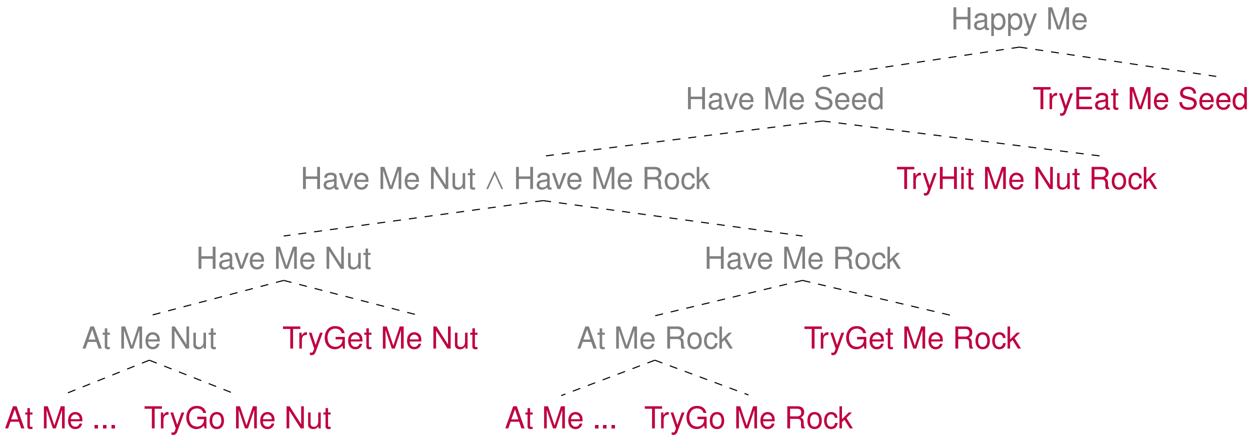
The model also assumes a set of learned **prediction rules**:



E.g. Have Me Rock (a) is composed of At Me Rock (c) followed by TryGet Me Rock (b).

Here, a, b, and c might be connected by a 'cause' elementary predication (dashed lines).

First, distinguish terminal (simple, observed) and nonterminal (complex, hidden) events:



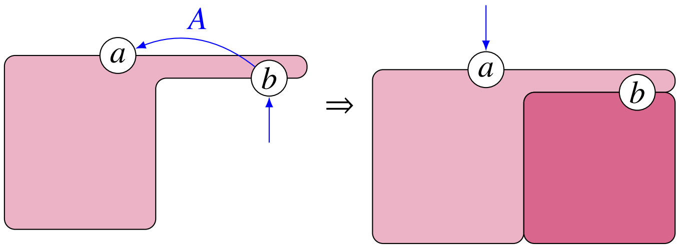
Note: in a binary-branching structure there are equal numbers of terminal and nonterminal events.

We predict this structure by guessing one terminal and one nonterminal branch at every observation.

Complex ideas can now be assembled by connecting observed events to event fragments...

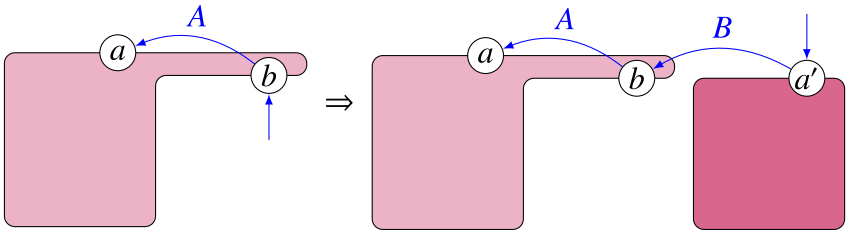
- **Terminal** decision (add observed event and connect to existing event fragment, or don't):

Yes-match result (set current prediction):



(Note that this replaces an event fragment with a complete event in associative memory.)

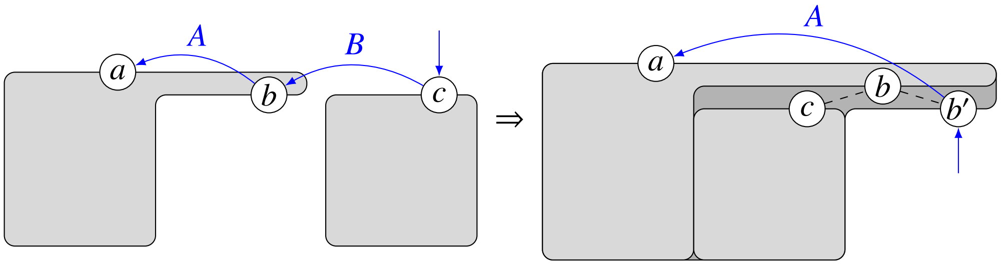
No-match result (check types, store cued association from a' to b, set current prediction):



(Note that this just adds a complete event to associative memory.)

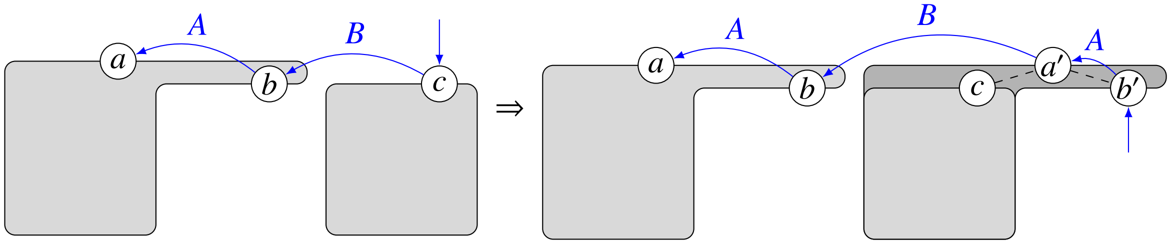
- Nonterminal decision (apply prediction rule and connect resulting event fragment, or don't):

Yes-match result (check types, apply rule, store cued association from b' to a):



(Note that this replaces an event fragment and a complete event with an event fragment.)

No-match result (apply rule, store cued association from b' to a' and a' to b:



(Note that this replaces a complete event with an event fragment in associative memory.)

Matching can be implemented in simple neural networks, generalized by procedural learning.

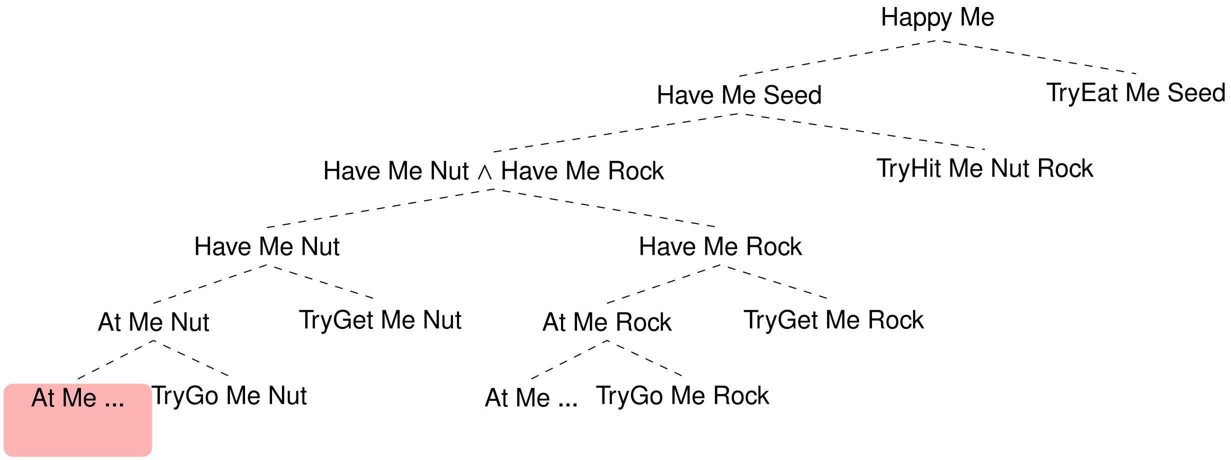
These operations can recognize any branching event structure using a minimum amount of memory.

10.4 Example recognition by hierarchic sequential prediction

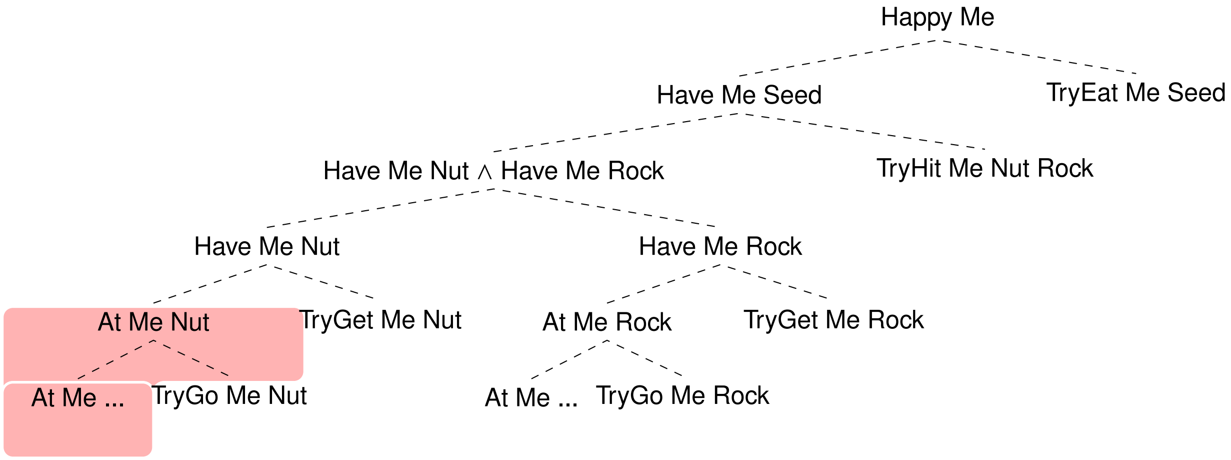
Here is an example of recognizing a complex plan from observations.

The events and event fragments will be drawn onto the phrase structure tree as they are recognized.

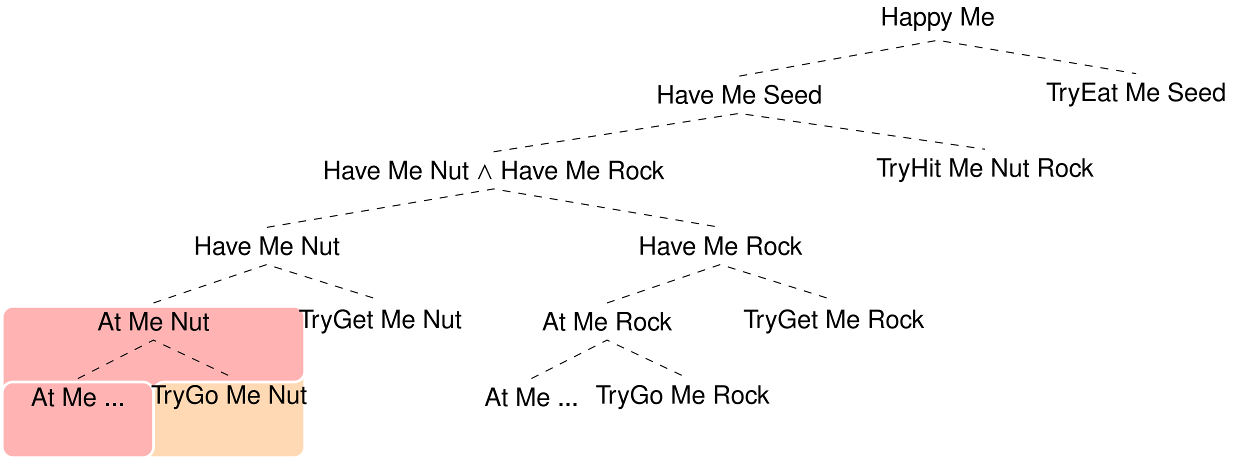
Terminal: start w. observation of At Me (wherever), don't match it to expectation of complete plan:



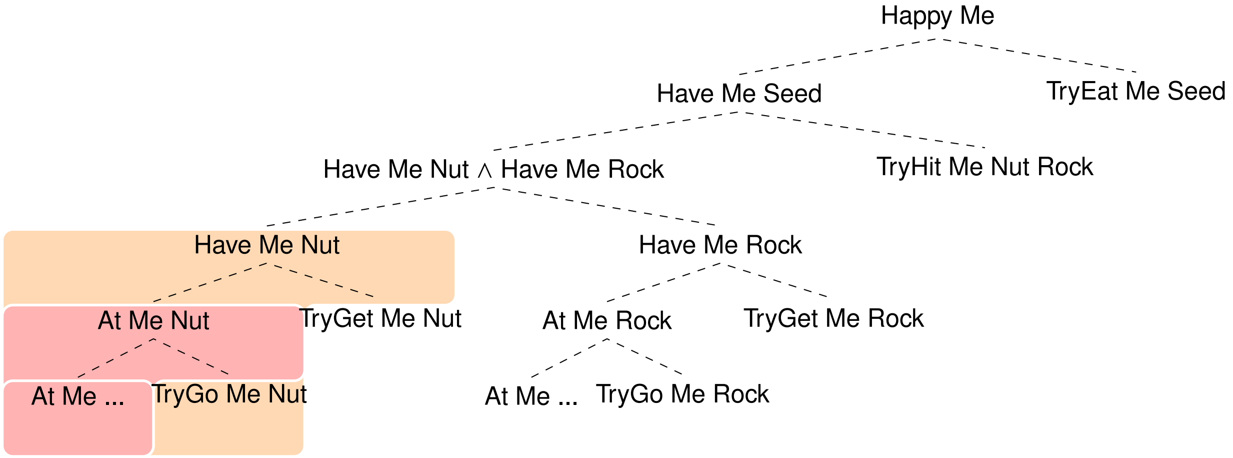
Nonterminal: expect TryGo Me Nut, outcome At Me Nut, don't match expectation of complete plan:



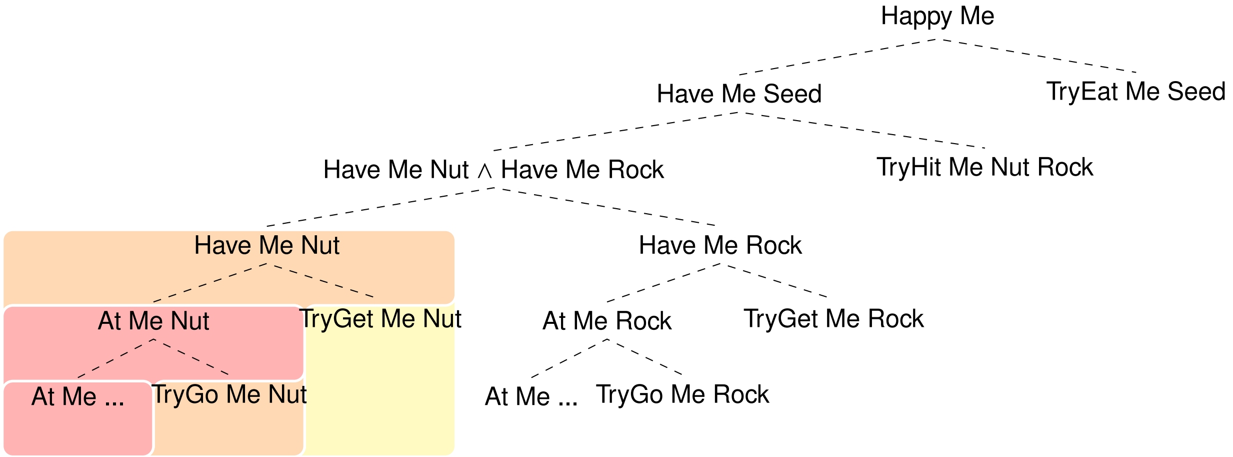
Terminal: observe TryGo Me Nut, match to expectation of TryGo Me Nut, making complete event:



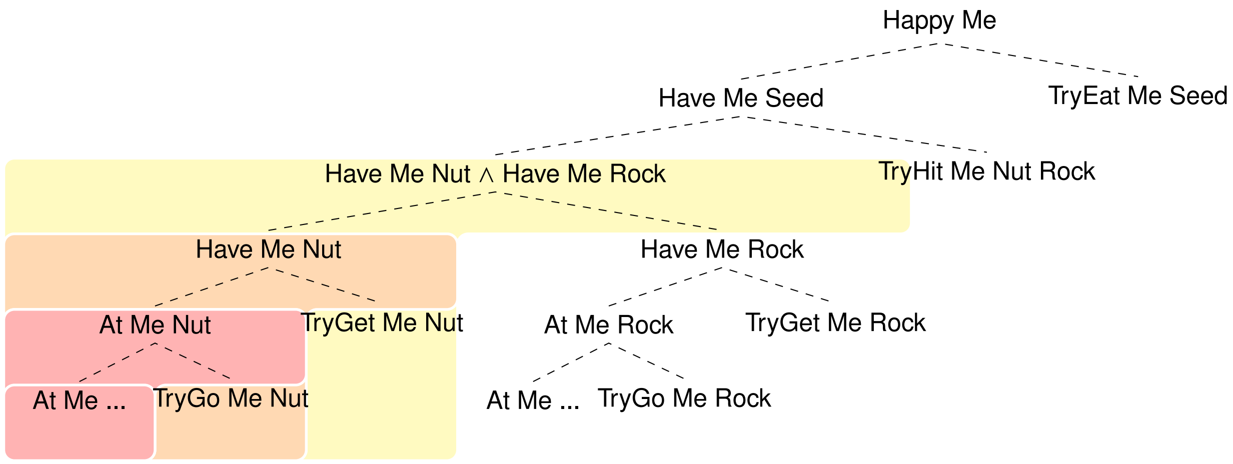
Nonterminal: expect TryGet Me Nut, outcome Have Me Nut, don't match to the completed plan:



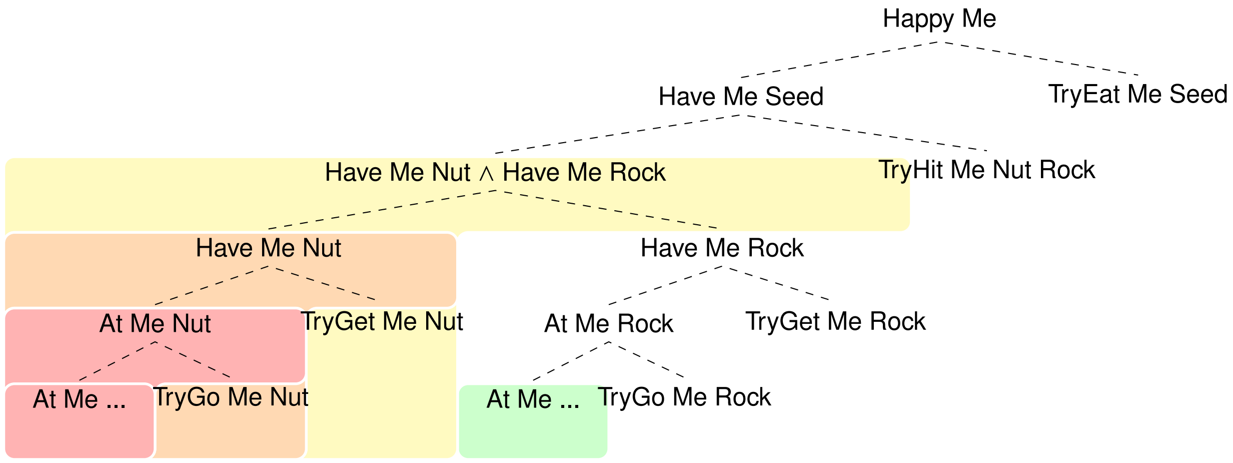
Term: observe TryGet Me Nut, match expectation of TryGet Me Nut in previous event fragment:



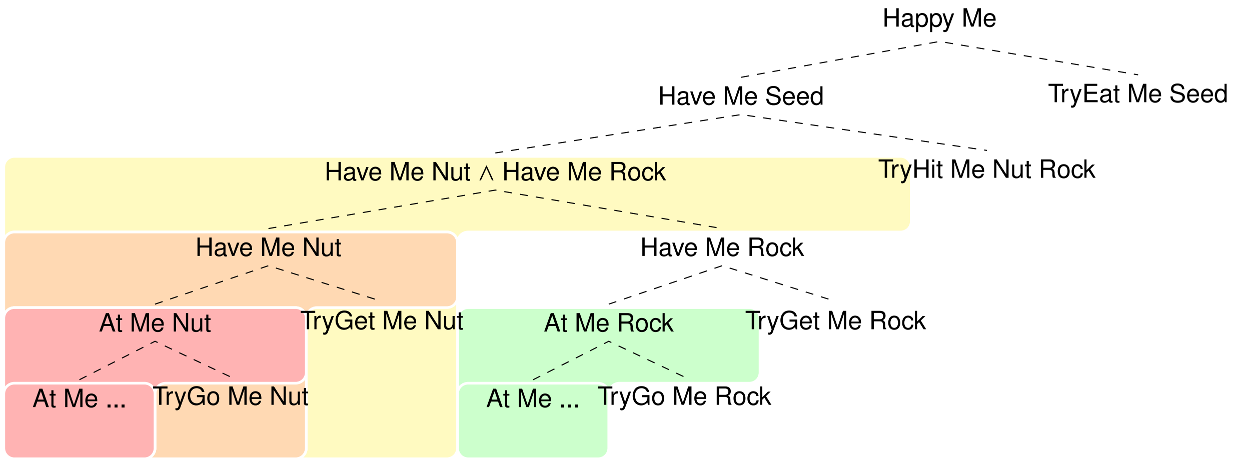
Nonterm: expect Have Me Rock, outcome Have Me Nut ∧ Have Me Rock, don’t match as complete:



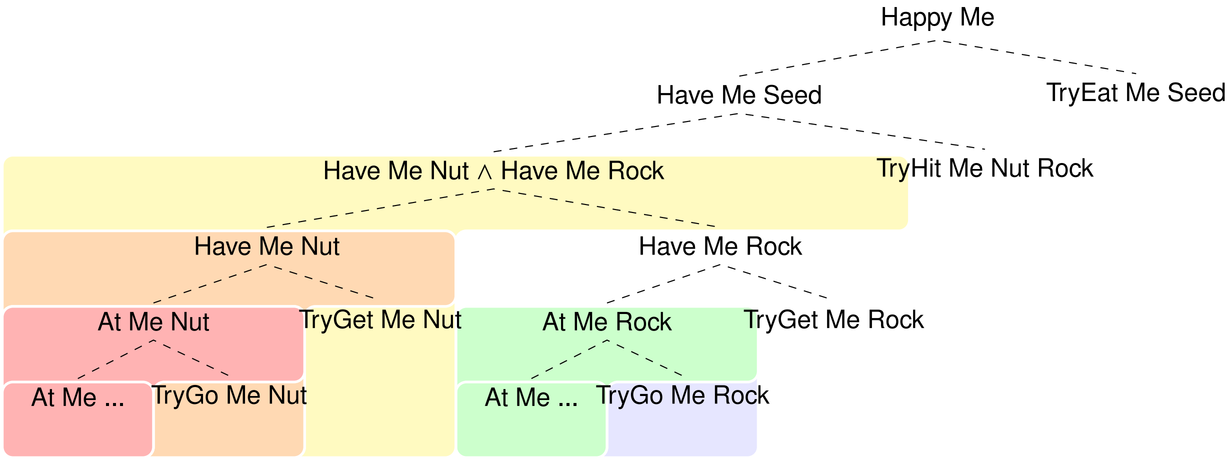
Term: observe At Me (wherever), don’t match expectation Have Me Rock, creating separate event:



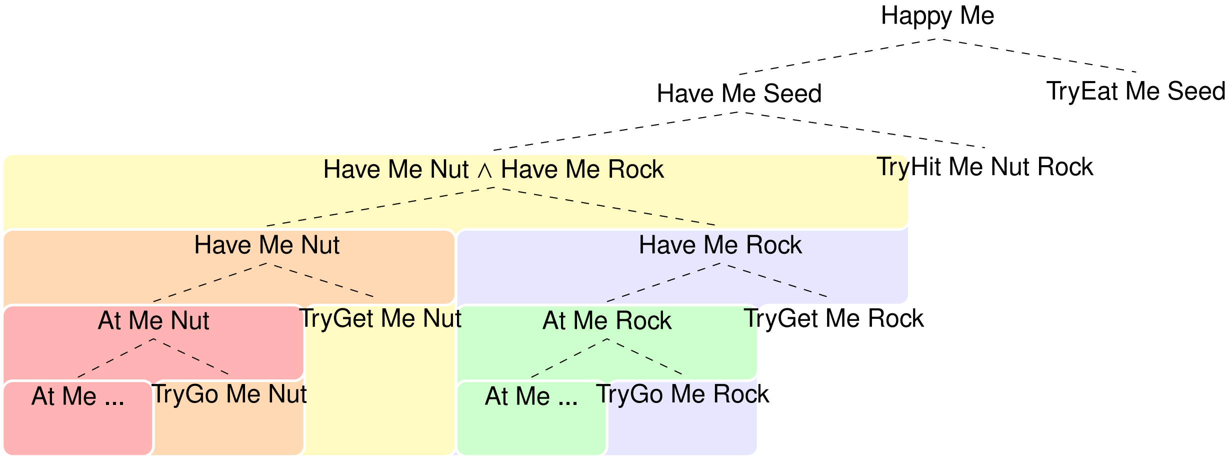
Nonterm: expect TryGo Me Rock, outcome At Me Rock, don’t match expectation of Have Me Rock:



Term: observe TryGo Me Rock, match to expectation of TryGo Me Rock, forming complete event:



Nonterm: expect TryGet Me Rock, match outcome Have Me Rock, forming single event fragment:



10.5 Practice

Continue the process for one more terminal and non-terminal decision.

Draw the event fragments that exist immediately after observing TryGet Me Rock. Specifically:

1. What will be the terminal decision result, and what event will exist afterward?
2. What will be the non-terminal decision result, and what fragment will exist afterward?

References

[Botvinick, 2007] Botvinick, M. (2007). Multilevel structure in behavior and in the brain: a computational model of Fuster's hierarchy. *Philosophical Transactions of the Royal Society, Series B: Biological Sciences*, 362, 1615–1626.

[Fuster, 1990] Fuster, J. M. (1990). Behavioral electrophysiology of the prefrontal cortex of the primate. *Progress in Brain Research*, 85, 313–324.

[Johnson-Laird, 1983] Johnson-Laird, P. N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge, MA, USA: Harvard University Press.