Perception-Action Hierarchy

"If I have seen further it is by standing on the shoulders of giants"
Sir Isaac Newton (1643-1727 B.C.)

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Adaptron Inc.

The Perception-Action Hierarchy is the architecture used by Adaptron to remember what was recognized and what was done.
An important emphasis here is on the WHAT. It is sense and action device independent. It does not remember where something was recognized or done.
An example is you can see a square or feel it drawn on your back. Or you can draw a square with your finger, toe, tongue or eyes.
This presentation describes how this hierarchy is built out of binons and how it works.
A lot more detail can be found in previous presentations.
A lot of these concepts are not new.
What I have done is aggregate the ideas that too-many-to-mention brilliant scientists before me have invented and
published in the areas of psychology, cognitive science, artificial intelligence, neuroscience, psychophysics and robotics.

Contents

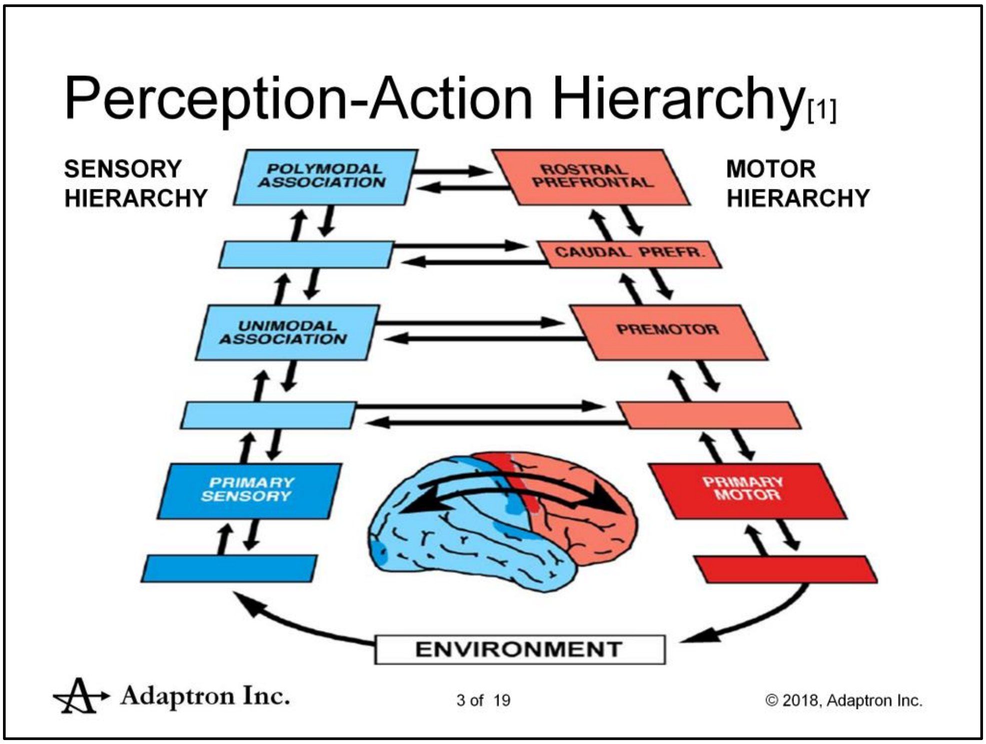
- Perception-Action hierarchy
- The binon
  - Structure
  - Temporal dynamics
- Actions
- Expectations

In this presentation I explain these subjects from a functional and mechanistic perspective

because it is these aspects that allows for them to be modeled in software.

This may be quite different from how they are explained in biology, psychology or cognitive science.

After providing an introduction to the P-A hierarchy and binons I go on to explain how binons are combined and work together to control perception and action.



This is the classic Perception-Action hierarchy as illustrated by Joaquín M. Fuster. Read more about it on Wikipedia at: https://en.wikipedia.org/wiki/Motor_cognition#Perception-action_coupling

I call it a Behavioural Perception-Action Hierarchy or a Stimulus Response P-A Hierarchy.

In Fuster's terminology it is the Sensory-Motor Perception-Action Cycle.

Stimuli from the environment enter on the bottom left via the senses.

They are then recognized in the sensory hierarchy. This is Perception.

Motor responses (actions) leave on the right via action devices and have an effect on the environment.

The motor hierarchy on the right decomposes complex action into more primitive actions.

The horizontal arrows in between associate perceptions with actions.

These are the action and expectation habits described on the next slide

Perception-Action Hierarchy

- Actions – sense to motor associations
  - If perceive stimulus Then do response
  - Production rules
  - Command Neurons
- Expectations – motor to sense associations
  - If done response Then expect stimulus
  - Part of forward models [2][3]

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An Action is equivalent to:

A Production Rule in AI = If perceive stimulus then do response in Software = a Command Neuron in neuroscience.

An Expectation is equivalent to:

If done response then expect stimulus = part of the forward model in motor control in neural networks and neuroscience.

The complete forward model is actually: given a stimulus and a response you can expect the next stimulus.

Properties of the P-A Hierarchy

- It learns bottom-up
  - Babbling, practicing, automaticity
- Reuses learnt perceptions and actions
  - Compositional structure
  - Combines more general simple properties/features/responses
  - Produces more specific complex representations/concepts/skills

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A mature P-A hierarchy takes years to learn. There are three stages to learning; babbling, practicing and automaticity.

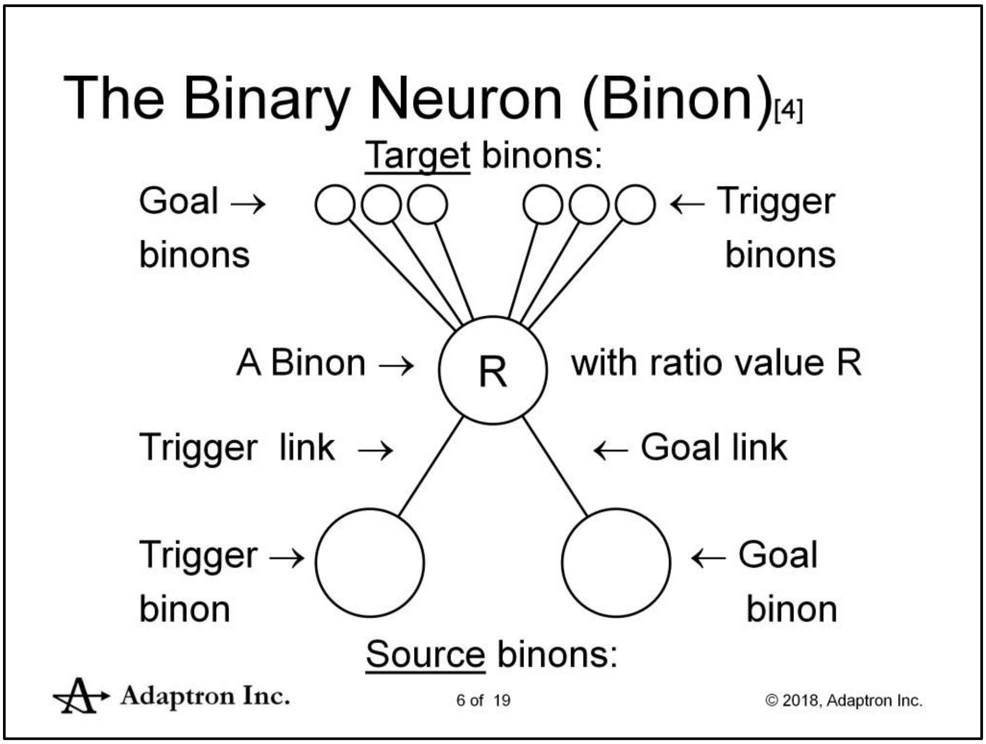
Babies use babbling to perform random motor and speech acts. They practice the ones that are successful and remember them.

Then they reuse them and incorporate them into more complex actions. Again practicing and remembering the successful ones.

The simpler learnt ones can then be done automatically without thinking about them as the more complex actions that use them are performed.

Learning takes place bottom-up from the more general purpose and simpler actions to the more complex ones, just like learning to recognize things.

So the P-A hierarchy is a compositional structure. Simpler things are combined and reused in more complex and more specific things.



A binon is a neural node in a network.

It only has two source nodes but connects with multiple target nodes.

Source binons are closer to sensors and action devices so are more general.

They represent the more primitive properties, features and responses.

Target binons are more specific because they combine source binons. They represent a combination of properties, features and responses.

Source binons are combined to form a target binon. This is a compositional structure, binons are added together.

Having two source binons results in a binary hierarchy when viewed from the top down.

But multiple target binons produces a lattice network when viewed bottom-up.

Trigger source binons are on the left and Goal source binons are on the right.

Since Binons only represent one thing they are reused by multiple target Binons. They can be part of many more complex things.

This is why they are linked to many target binons.

A binon may be the trigger for many trigger target binons.

And it may be the goal of many goal target binons.

The Binon

- Spatial and temporal binons
  - Parallel perception and action - [+]
  - Sequential perception and action – [→]
- No weights on links, no probabilities
  - Ratio values in the nodes
  - Deterministic – explainable logic
- Continuous learning – growing network
  - adds binons as it learns new patterns and actions

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There are basically two types of binons; spatial and temporal. The + and arrow appear under a binon to indicate their type.

The words “Trigger” and “Goal” make binons sound like a temporal thing but they can also be spatial.

For spatial recognition a binon represents a pattern of things in which the two parts (source binons) have occurred simultaneously.

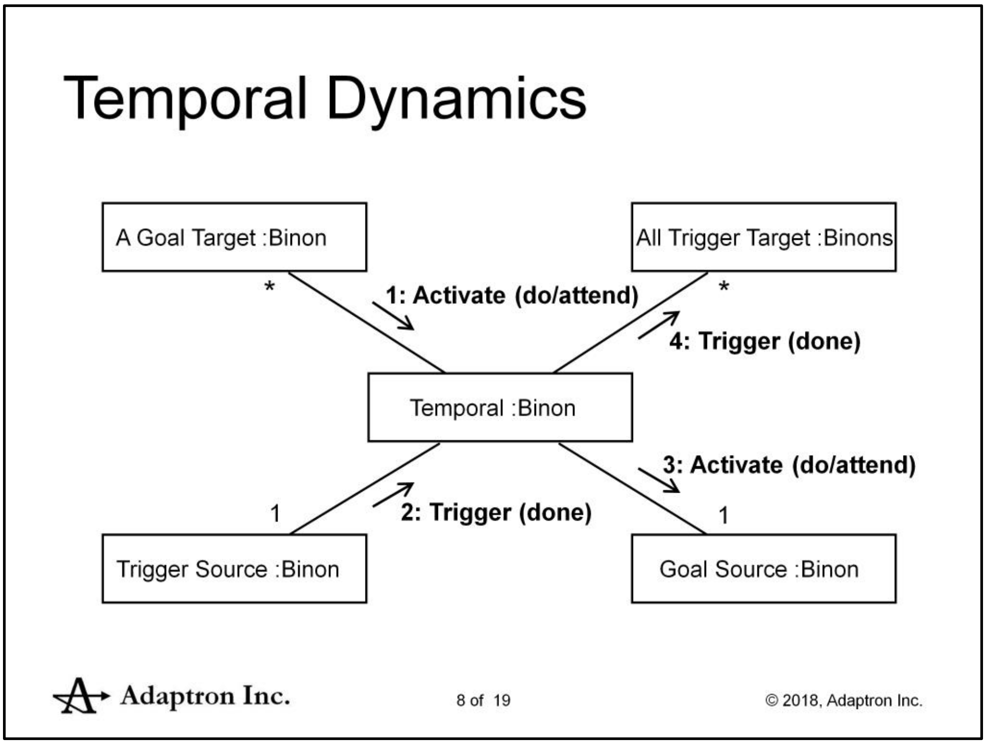
Temporal binons represent things that take place in time. They are necessary to recognize patterns such as speech but also to control actions and thinking.

Binons are deterministic. There are no probabilities involved and there are no weights on the links. This means that what they do and why they do it can be explained.

The only value a binon has its ratio value. This allows a binon to represent the relationship between its two source binons.

A network of binons is continuously learning. New binons are added to represent new patterns of stimuli and responses.

This means a binon network is an un-supervised ANN. However the growth rate is gradual and controlled – see the presentation on Learning for more details.



It is necessary to understand the behaviour of temporal binons to explain their role in controlling a P-A hierarchy.

This a UML communication diagram to illustrate how the wave of activation travels horizontally from left to right through a hierarchical network of temporal binons. All the binons on this diagram are temporal binons.

The arrows represent signals or messages in which one binon is saying to the next:

“I have recognized the trigger I was expecting, I have done my job, now you (the next binon) can start doing or continue to do your job”.

Activate signals are messages to start doing while trigger signals are messages to continue doing. After a temporal binon has been activated it waits for its trigger source to fire. Then it can fire all its out going links – trigger targets and goal source.

The dynamic control flow is the same for all temporal binons. It’s like turning the normal spatial recognition dynamic behaviour on its side.

Rather than flowing up the tree the wave of activity flows in time from left to right.

1: A Goal Target binons activates the process.

2: The temporal binon waits for the trigger source binon to fire which means it is done.

3: The temporal binon then activates the goal source binon and

4: All the trigger target binons are notified by the temporal binon that the action has been done.

In psychology the do activation is the same concept as preparatory motor set. And the attend activation is the same concept as perceptual set.

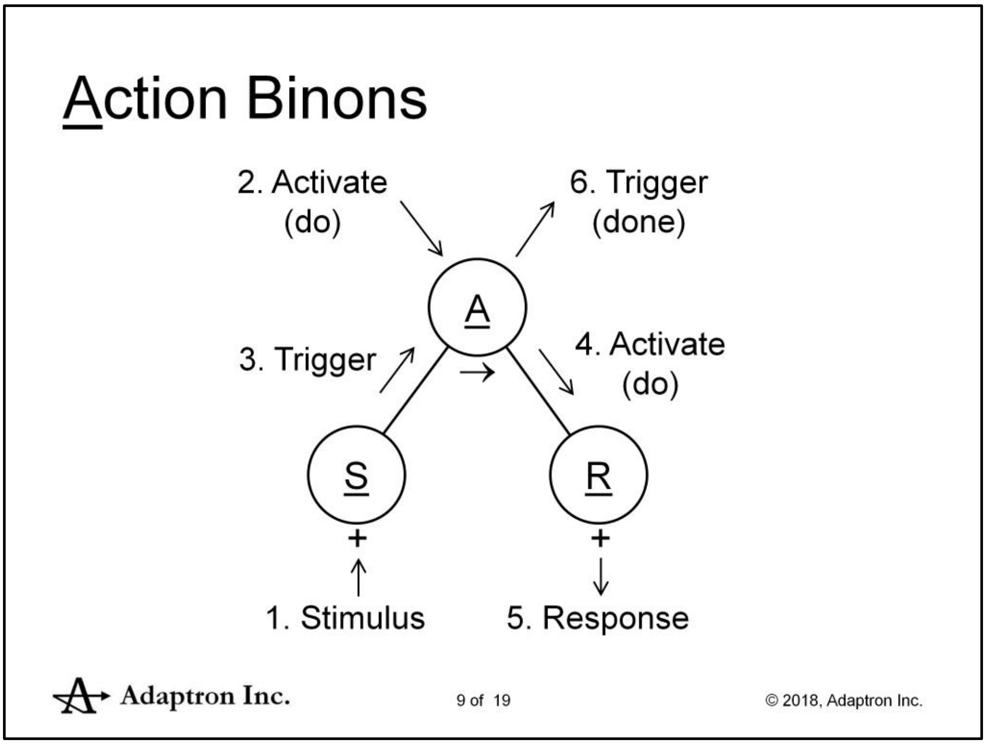
Remember that a binon can be linked to many goal and trigger target binons.

So when a goal target binon activates a temporal binon it is saying to it get ready to handle your trigger source should it occur.

Since there are many goal targets of the temporal binon it can be used by its many goal target binons to handle what could happen next.

This means that when a temporal binon fires it triggers many trigger target binons.

If any of these have been activated then they will activate their goal source binons. They will all be waiting for their trigger source to occur but only one will occur.



The underlined letters in the binons indicate the role they play in the process.

But they are all binons with identical structure.

This interaction diagram captures the order in which the process takes place.

A S Stimulus binon represents and recognizes a stimulus from the environment (via the senses) or a combination of stimuli to represent concepts and objects.

A R Response binon represents and activates a simple or complex action in the environment (via action devices).

An A Action binon represents and controls what response to perform when a stimulus is recognized.

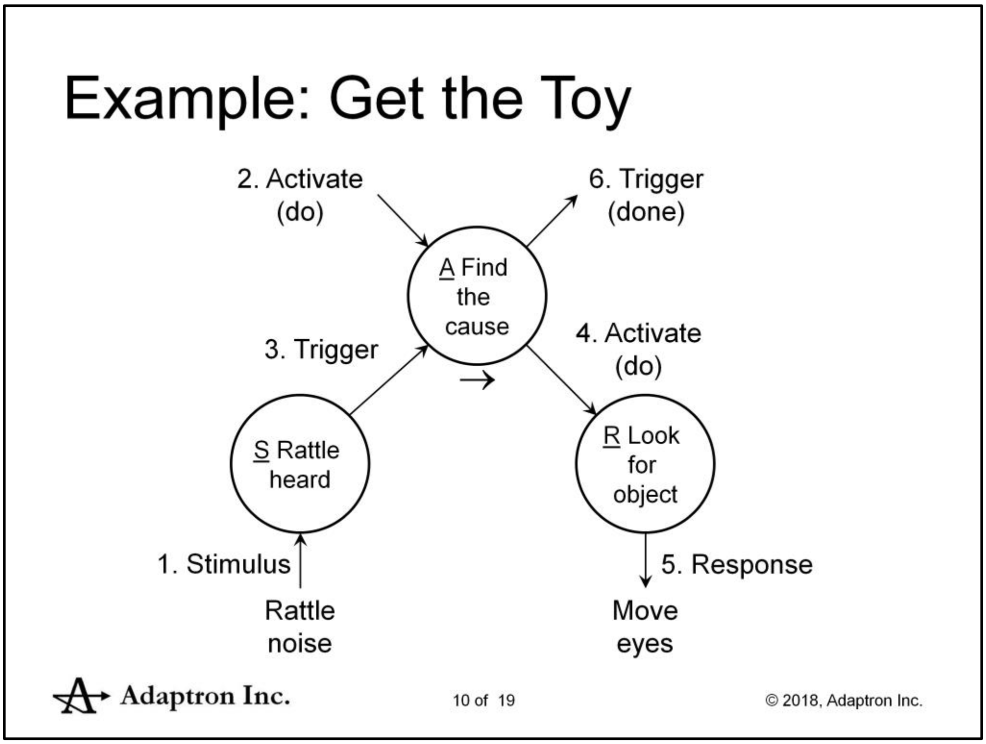
The process starts when a stimulus is perceived. This attracts attention and results in thinking. Thinking is not shown on this diagram it is described in the Thinking presentation. Thinking makes a decision to perform the process and activates the action binon to control the process.

The action binon is active but needs to be triggered by its trigger binon, the stimulus binon.

The stimulus has been recognized so the action binon is triggered. It now activates the response which gets done and the

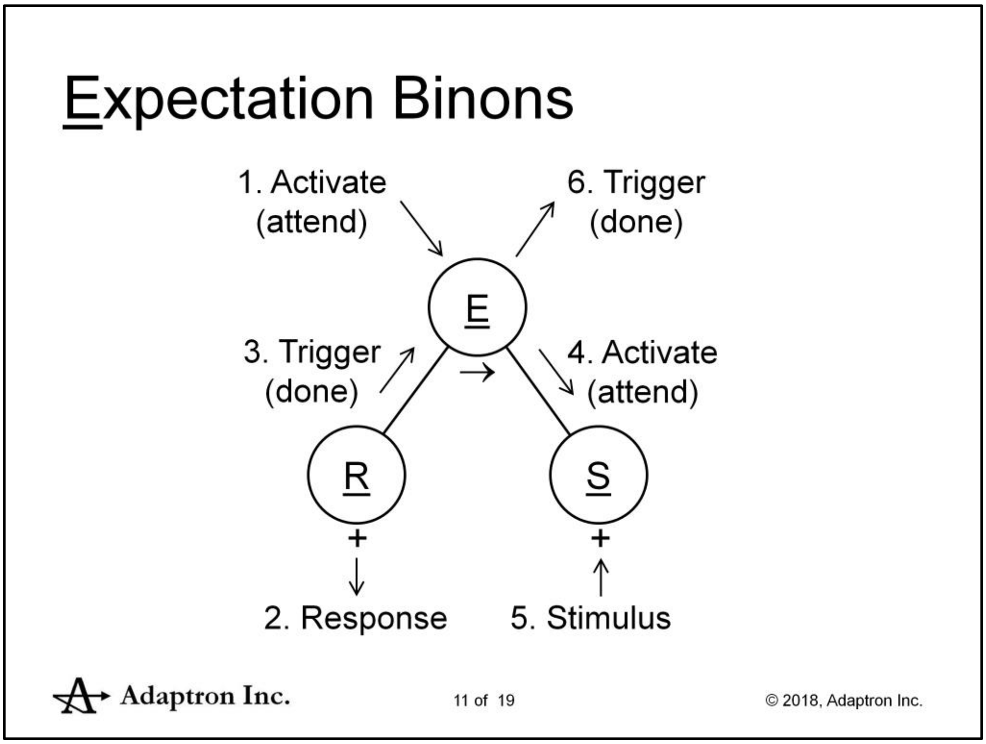
Action binon notifies all it trigger targets that it is done. Trigger targets will have to be activated if they are to do anything as a result.

If there are no activated trigger targets then the action habit is finished. Notice how the wave of activation flows from left to right.



All the examples in this slide and the ones that follow are based on the task of reaching for a toy that is heard and then seen.

This is the very first action habit in the task. It is triggered when the toy rattles and the response is the movement of eyes to locate it.



After performing a response you expect some resulting stimulus.

This interaction diagram captures the order in which this process takes place.

The expectation binon controls the process. An expectation binon is something that is done. The initial 1. activation to focus attention originates from a decision in the thinking process which is described in the Thinking presentation.

The expectation binon is active but needs to be triggered by its trigger binon. Its trigger is the response binon saying it has finished doing what it was asked to do by the previous action binon from the previous slides.

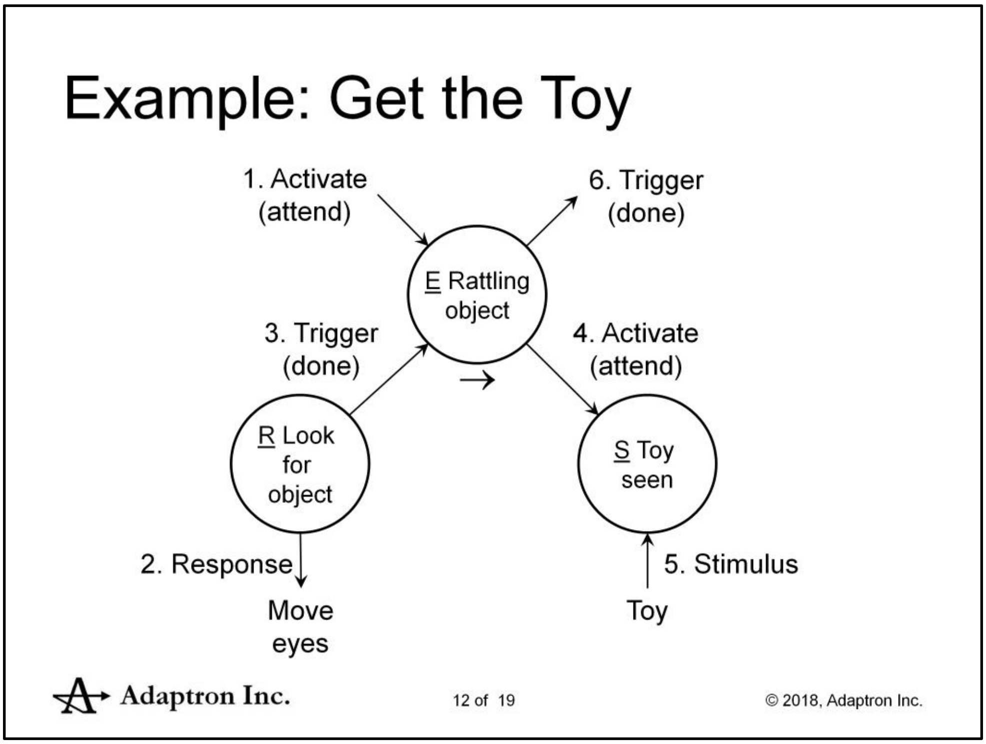
So when the response is done the expectation binon is 3. triggered. It now 4. activates the stimulus binon to attend to the expected result.

It basically requests the stimulus binon to focus its attention. If this 5. stimulus occurs the stimulus binon will fire.

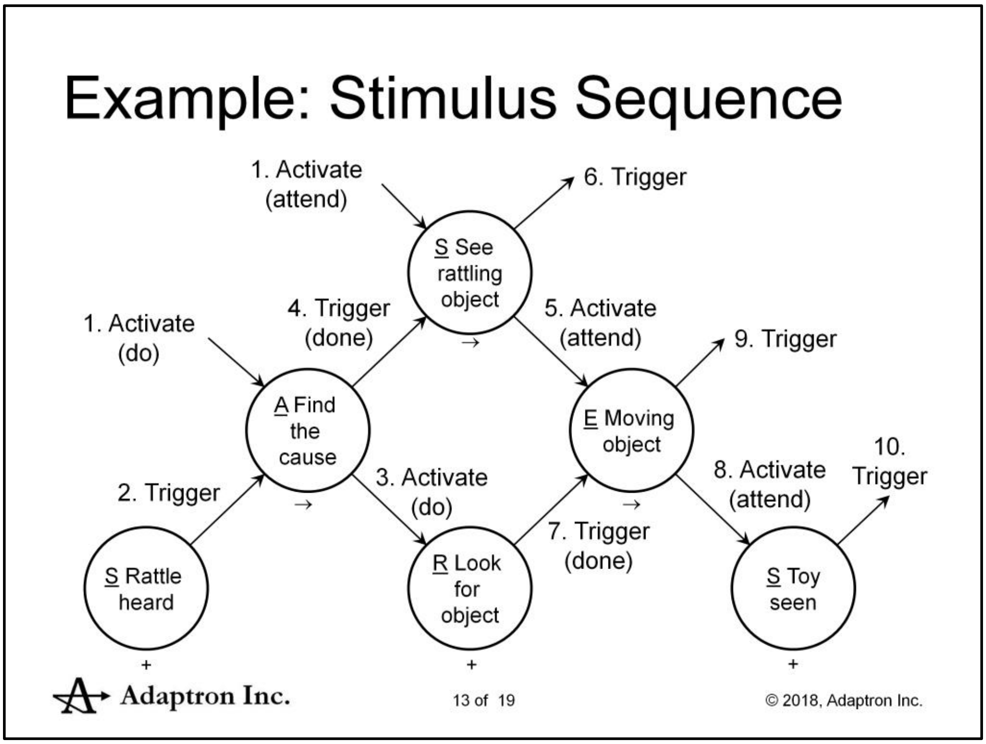
Without waiting for the stimulus binon to recognize its pattern the expectation binon 6. notifies all it trigger targets that it is done.

Trigger targets of the expectation (not shown) will have to be activated if they are to do anything as a result of the 6. Trigger(done).

If there are no activated trigger targets then the expectation habit is finished. Again, notice how the wave of activation flows from left to right.



Once your eyes have moved to where the noise originated you are expecting to see the rattling object. What you see is a toy.



Once a Response binon has been done it may trigger numerous Expectation binons.

Each one will activate a Stimulus binon to pay attention.

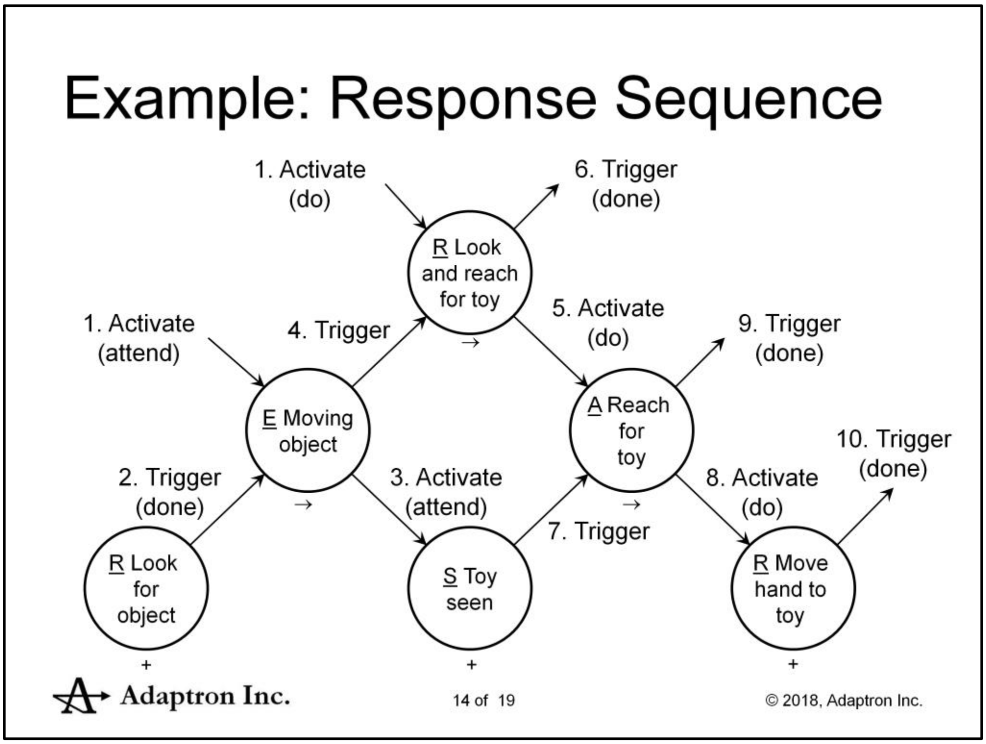
The stimulus sequence captures the information that is found in the forward model in motor control in neural networks and neuroscience.

This structure also captures the information that is found in the Backward or Inverse model in motor control in neural networks and neuroscience.

The inverse model says that given the current stimulus and a desired future stimulus then perform the response.

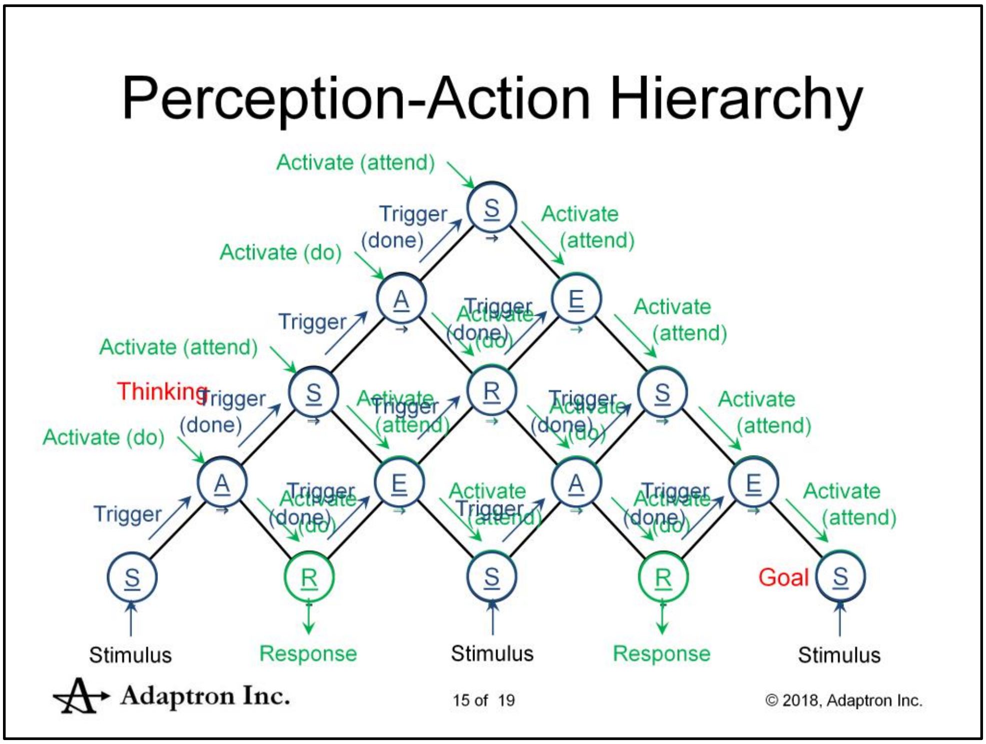
The Response binon may be a "do nothing" response. This means there is no action performed and the action binons and response binons could be left out.

The structure then becomes a series of spatial stimulus binons controlled by a series of expectations binons. This would be the case when you are listening to music.



Looking along the bottom row of spatial binons you can see a Response-Stimulus-Response sequence.

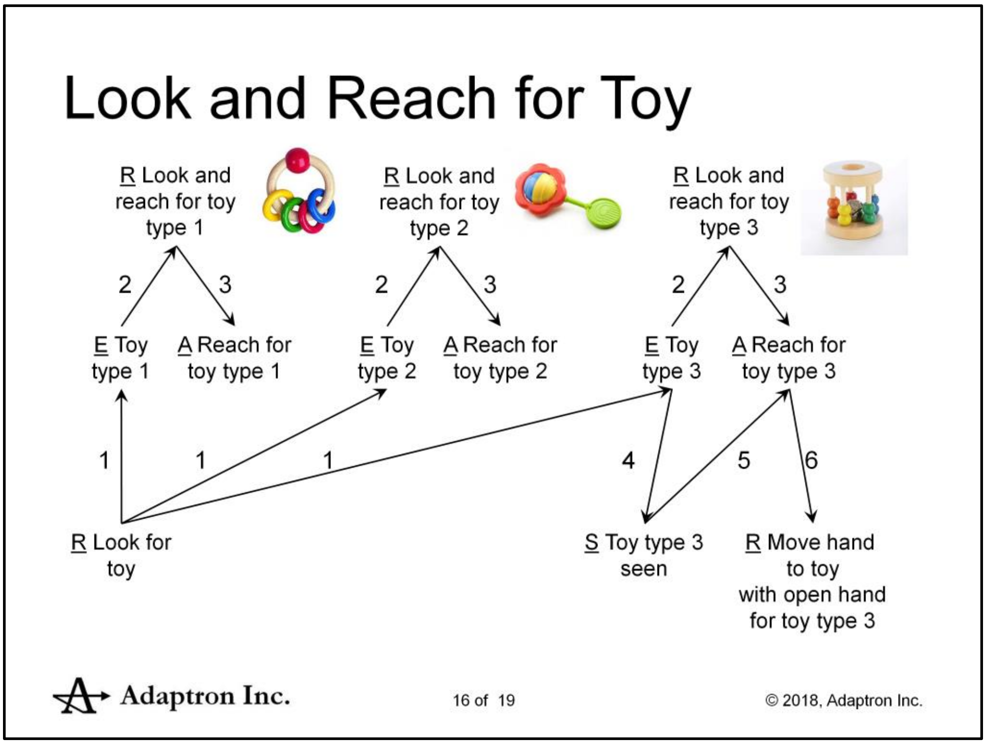
This is now represented as a temporal response binon at the top of the hierarchy and can be reused in more complicated actions.



This is an animated slide:

The result is an integrated recognition & action network in which lower level action, expectation, temporal stimulus and temporal response binons can be reused to form higher level behaviour.

But how does it get started? That is where thinking comes in. A one step look ahead uses the network to determine if the action or expectation binon is worth doing. For intrinsic motivation this is driven by the temporal binon being novel and therefore worth practicing / repeating. If it is familiar then a two or more step look ahead will search out something worth doing. If thinking that much ahead has not been learnt and nothing was found worth doing then babbling will be done.



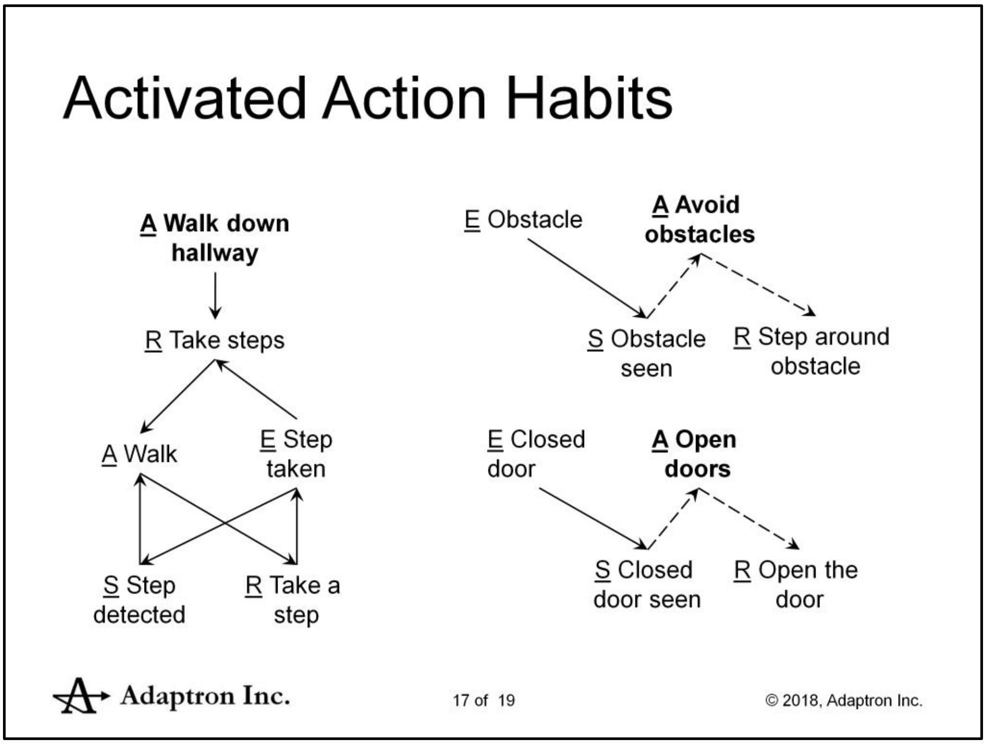
Remember that a stimulus binon can trigger multiple action binons and a response binon can trigger multiple expectation binons.

If you have experience hearing toys rattle and looking for them then from the sound you may think it is one of these three toys.

In this example the look for toy response has triggered three expectation binons simultaneously. One for each toy type. However only one type of toy will be seen, toy type 3.

This will trigger the one action that can grab such a toy.

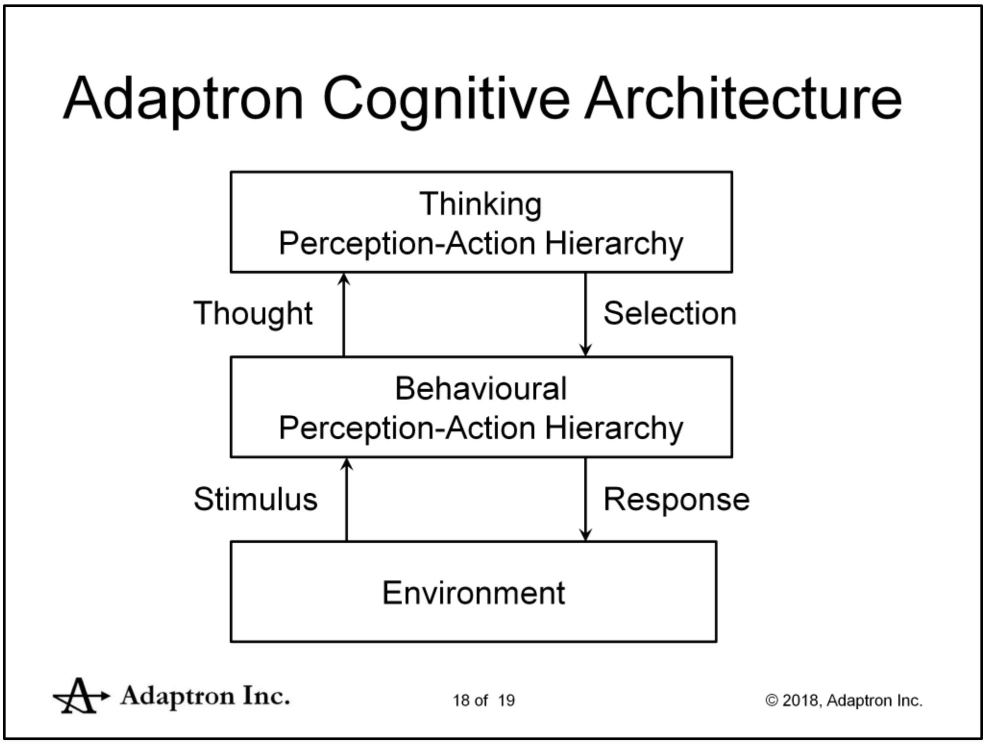
It will be the one that uses the correct open hand position in its response.



Multiple action habits can be active simultaneously. When performing any complex task one has to be ready to handle unexpected events.

In this example of walking down a hallway two other action habits, Avoid obstacles and Open doors, are active ready to start should their trigger stimulus be encountered.

Walking is a good example of a repetitive action habit.



In the Adaptron Cognitive Architecture there are two perception-action hierarchies (P-A hierarchies)

The behavioural one learns to act in the real world. It contains memories of its experiences.

The thinking perception-action hierarchy uses the memories in the behavioural one as its environment. A model of reality as experienced.

Recalled memories are its stimuli, its thoughts. Its responses are the selection of associated memories for recall and selection of actions to perform.

The thinking P-A hierarchy contains memories of its thoughts. It learns to think based on the same learning principle of the behavioural P-A Hierarchy.

Additional levels of perception-action hierarchies, e.g. a meta-thinking P-A hierarchy, could be added if you wanted to be able to think about your thoughts.

References

[1] Fuster, Joaquín M. (2003). Cortex and Mind, Unifying Cognition. Oxford University Press, New York.

[2] Grush, Rick (2004). The emulation theory of representation: Motor control, imagery, and perception. Behavioral and Brain Sciences (2004) Vol. 27, pp 377–442

[3] Miall R.C. and Wolpert D.M. (1996). Forward Models for Physiological Motor Control. Neural Networks, Vol. 9, No. 8, pp 1265-1279

[4] Martensen, B. N. (2013). Perceptra: A New Approach to Pattern Classification Using a Growing Network of Binary Neurons (Binons). In R. West & T. Stewart (eds.), Proceedings of the 12th International Conference on Cognitive Modeling, Ottawa: Carleton University.