Perception-Action Hierarchy and its Implementation Using Binons (Binary Neurons)

"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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Abstract:
The perception-action hierarchy contains a model of the environment as experienced based on what has been recognized and done. This presentation gives a mechanistic/functional explanation of how binons(binary neurons) are used to represent and implement this hierarchy. Two kinds of temporal binons are used to learn and repeat experiences. They are the Action and Expectation control binons. They are equivalent to command neurons (production rules) and the prediction part of the motor control forward model. Learning takes place in the three stages of babbling(reusing), practicing and automaticity. The resulting hierarchy is a transparent, compositional, unsupervised, continuously growing, deep learning ANN.

The Perception-Action Hierarchy is part of the cognitive architecture used by Adaptron to remember what was recognized and what was done. An important emphasis here is on "WHAT". This is sense and action device independent. It does not remember where something was recognized or done. For example you can either see a square or feel it drawn on your back. That is sense independent. Or you can draw a square with your finger, toe, tongue or eyes. That is device independent. This presentation describes how this hierarchy is built out of binons and how it works. A lot more detail can be found in other presentations mentioned in the references. 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

- The Perception-Action Hierarchy
- Binons (Binary Neurons)
  - Structure
  - Temporal dynamics
- Actions
- Expectations
- Many simultaneously active binons
- References

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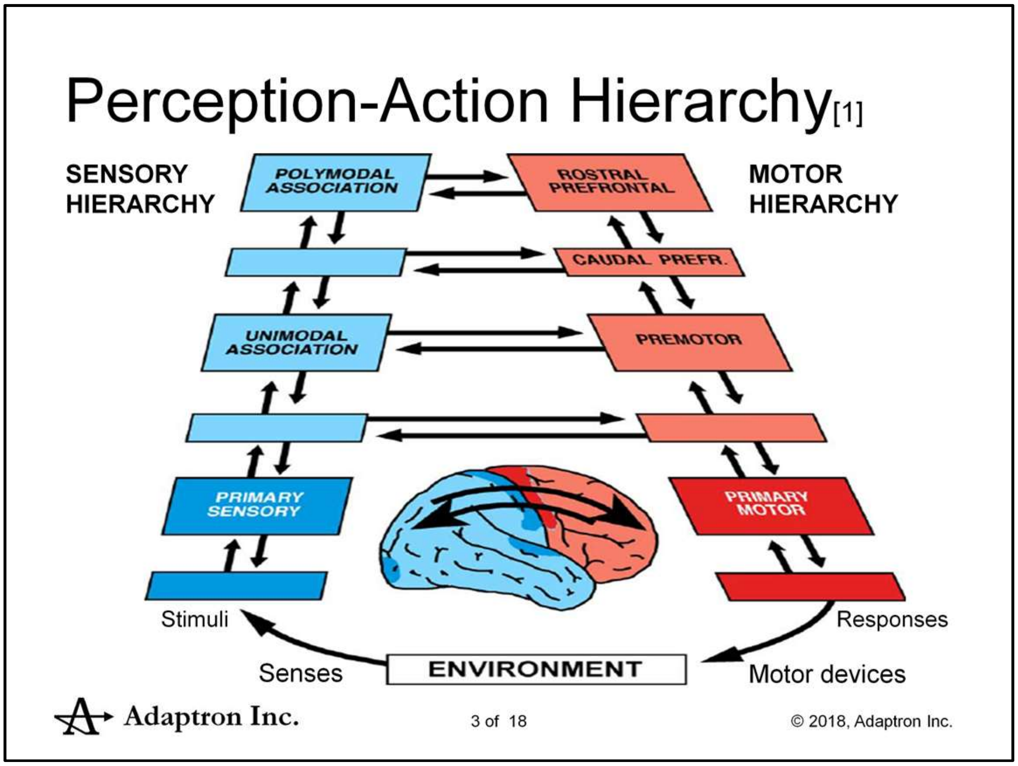
In this presentation I explain these subjects from a functional and mechanistic perspective. I'm interested in the principles of operation because I want to model them in software.

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 both 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 recognized by the sensory hierarchy on the left. It combines simpler stimuli into more complex multi-modal perceptions.

Motor responses (actions) leave on the right via motor/action devices and have an effect on the environment. The motor hierarchy on the right decomposes complex actions into more primitive actions.

The horizontal arrows in between the two hierarchies associate perceptions with actions. These are the action and expectation habits described in this presentation.

Perception-Action Hierarchy

- Actions – sense to motor associations
  - Production rules
  - **If** perceive a stimulus **Then** do a response
  - Command Neurons
- Expectations – motor to sense associations
  - **If** done a response **Then** expect a stimulus
  - Part of the forward model in motor control [2][3]

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Actions are the sense to motor associations and are equivalent to:

= Production rules as in cognitive architectures such as ACT-R and SOAR

= **If** perceive a stimulus **then** do a response

= Command Neurons in neuroscience.

Expectations are the motor to sense associations and are equivalent to:

= **If** done a response **then** expect a stimulus statements

= Part of the forward model in motor control in neural networks and neuroscience.

The complete forward model says: “Given a stimulus and a response you can expect the next stimulus”.

Properties of the P-A Hierarchy

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

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

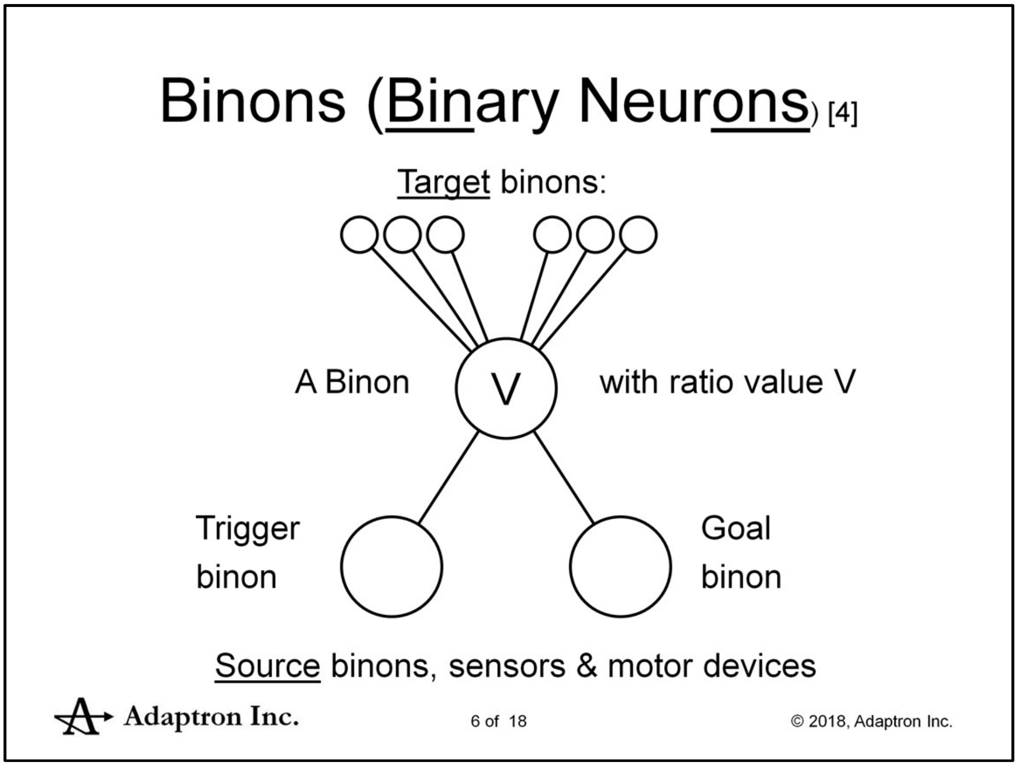
Babies use babbling to perform random motor and speech acts. These are reused and incorporating into more complex actions.

They remember the ones that are successful and practice them.

Learnt ones can then be done automatically without thinking about them. These automatic ones are then reused and incorporated into more complex actions.

Learning takes place bottom-up from the more general purpose and simpler actions to the more complicated ones. This is exactly the same for learning to recognize things.

The P-A hierarchy is a compositional structure. Simpler things are combined and reused to form more complex and more specific things.



A binon is a neural node in a network. It has two source nodes but connects with multiple target nodes. Source binons are closer to sensors and motor/action devices. So they are more general. Source binons represent the more primitive properties, features and responses. They are reused by multiple target Binons.

Target binons are more specific. They represent combinations of properties, features and responses.

The words “Source” and “Target” are used to describe the roles played by binons based on the level of complexity. So this is a compositional structure.

The words “Trigger” and “Goal” are used to describe the roles played by binons based on their left or right relationship.

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

The Binon

- Spatial and temporal binons
  - Parallel perception and action [+]
  - Sequential perception and action [→]
- No weights on links, no probabilities
  - Explainable
  - Ratio values in the nodes – V
- Continuous learning – growing network
  - adds binons as it learns new patterns and actions [5]

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There are two types of binons: spatial and temporal. The “+” and “→” symbols appear under a binon to indicate these two types.

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

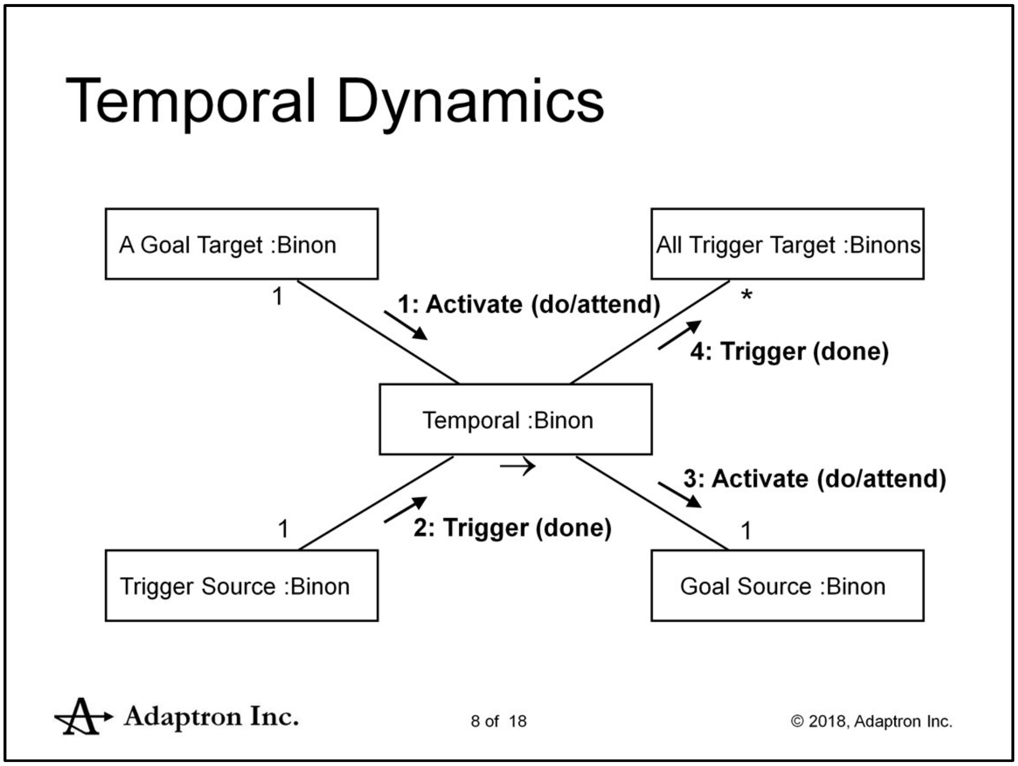
Temporal binons represent things that take place in sequence. They are necessary to recognize patterns such as speech but also to control actions and thinking.

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 clearly explained.

Binons contain ratio values that represent the relationship between the two source binons.

A network of binons is continuously learning and growing. It is an un-supervised ANN. New binons are added to represent new patterns of stimuli and responses.

However the growth rate is gradual and controlled – see the presentation on Learning for more details.



All the binons on this diagram are temporal binons. They control the behaviour of the Perception-Action hierarchy.

This interaction diagram illustrates how this works. The arrows represent signals or messages in which one binon is saying to the next:

"After I've been activated and have recognized the trigger I was expecting, I can tell you (the following binons) to start doing or continue doing your job".

The activate signals are messages or priming signals to start doing while the 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 – the goal source binon and all the trigger targets. Nothing will happen if the temporal binon is activated but the trigger source does not occur. Similarly nothing more will happen if the trigger source occurs but the temporal binon has not been activated.

This dynamic control flow is the same for all temporal binons. The wave of activity flows in sequence from left to right.

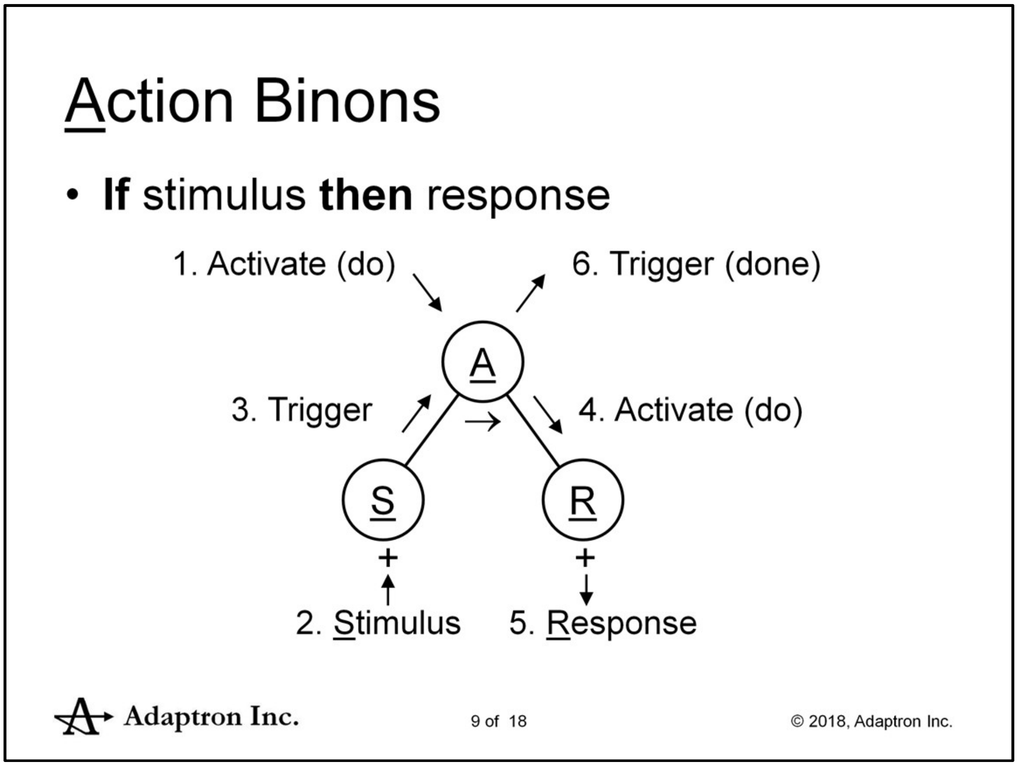
1: A goal target binon activates the process (do/attend).

2: The temporal binon waits for the trigger source binon to be recognized (done).

3: The temporal binon then activates the goal source binon (do/attend) and

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

In psychology the Activate(do) is the same concept as preparatory motor set. And the Activate(attend) is the same concept as perceptual set.



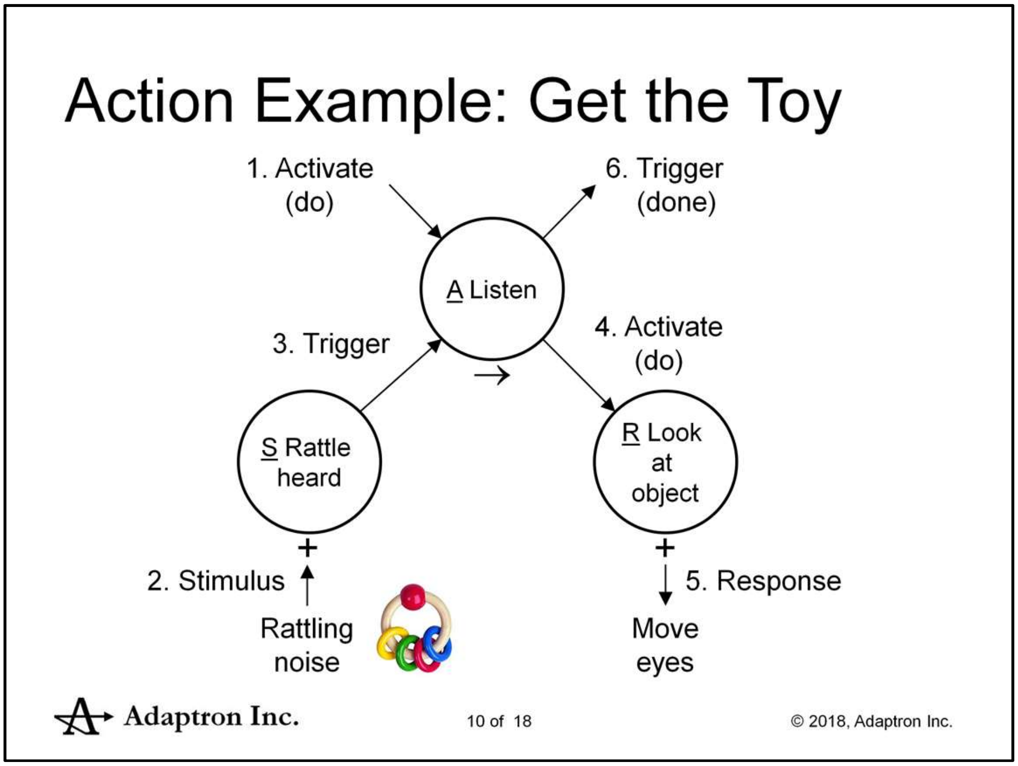
There are two types of temporal control binon: the action control and expectation control binon. This interaction diagram captures the order in which the action control process takes place. The underlined letters in the binons (S, A and R) indicate the role they play in the process. The process is equivalent to the If stimulus then response production rule.

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

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

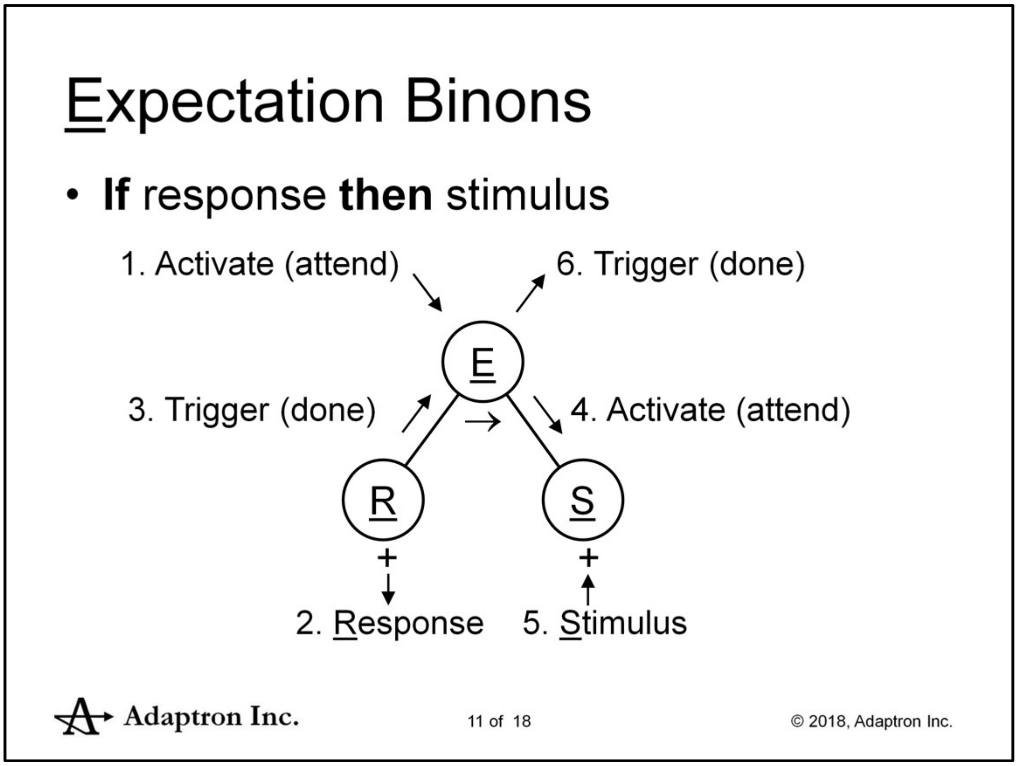
An Action binon represents and controls what response to perform when a stimulus is recognized.

The process starts when the action binon is activated (1). It is primed waiting for the stimulus to be recognized. When the stimulus is recognized (2) the action binon is triggered (3). The action binon then activates (4) the response which gets done (5). The action binon notifies all it trigger targets (not shown) that it is done (6). Any previously activated trigger targets will then be triggered. If there are no previously activated trigger targets then the action habit is finished.



This example and the ones that follow are based on the task of a baby hearing, seeing and reaching for a toy.

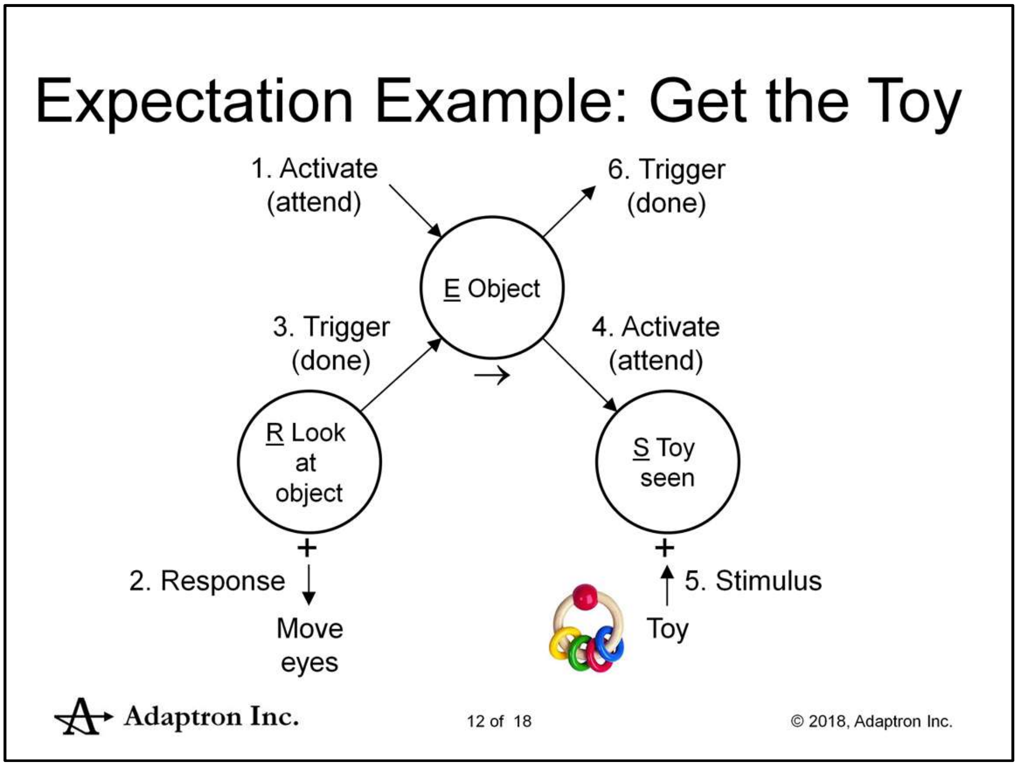
This is the very first action habit in the task. The baby is actively listening. It hears a rattling noise and it looks for the object by moving its eyes.



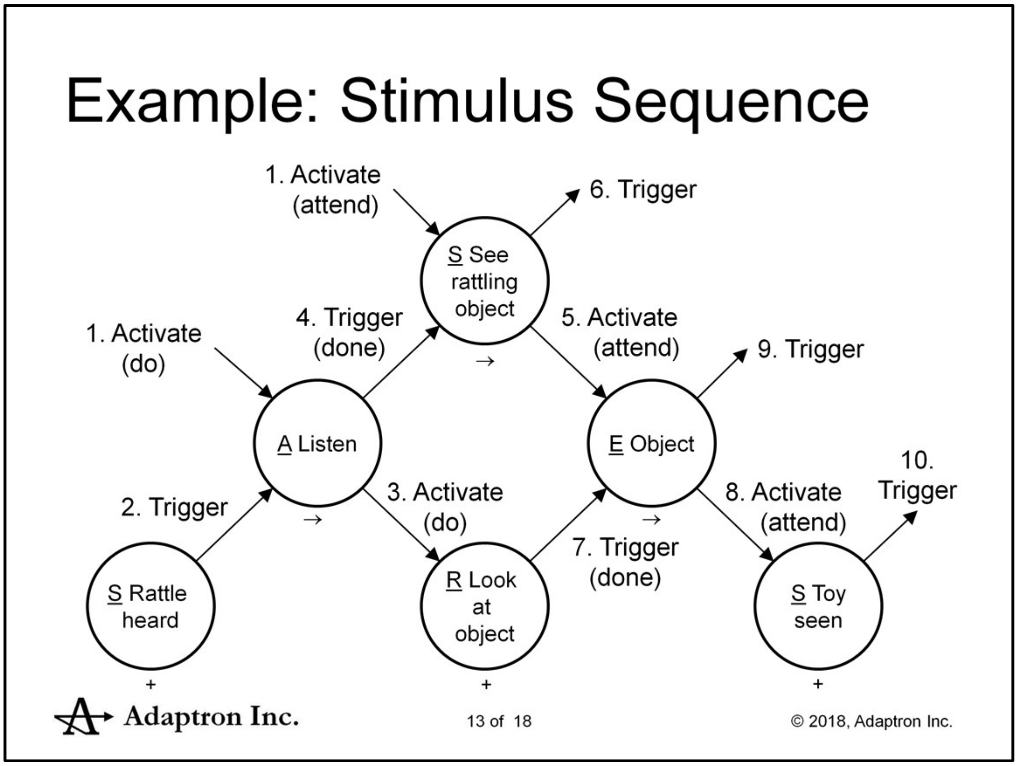
After performing a response you expect some resulting stimulus. This interaction diagram captures the order in which this expectation control process takes place. It is equivalent to the If response then stimulus production rule.

The Expectation binon represents and controls what stimulus to expect when a response is performed.

The process starts when the expectation binon is activated (1). It is primed, waiting for the response to be performed. The response will be performed if it has been activated by a previous action binon. When the response is performed (2) the expectation binon is triggered (3). The expectation binon then activates the stimulus binon (4) to attend to the expected result. If this stimulus occurs (5) the stimulus binon will trigger all its trigger target action binons (not shown). Without waiting for the stimulus binon to recognize its stimulus pattern the expectation binon notifies all it trigger targets (not shown) that it is done (6). Any previously activated trigger targets will then be triggered. If there are no previously activated trigger targets then the expectation habit is finished.



As an example; once the babies eyes have moved to where the noise originated it is expecting to see the rattling object. What it sees is a toy.

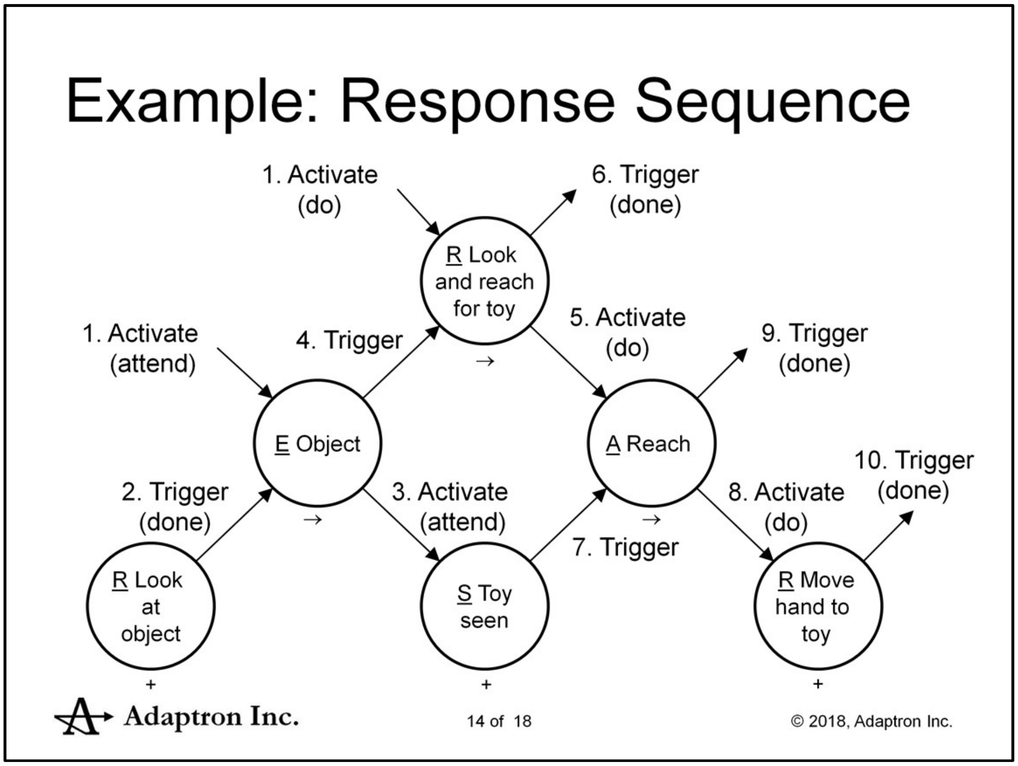


Combining the previous action and expectation examples produces a stimulus sequence at the top. Along the bottom row of spatial binons you can see the Stimulus-Response-Stimulus sequence. It starts with hearing the rattle and ends with seeing it.

This stimulus sequence is now represented as a temporal stimulus binon at the top of the hierarchy. The stimulus sequence can now be reused as the trigger source in more complicated action control sequences.

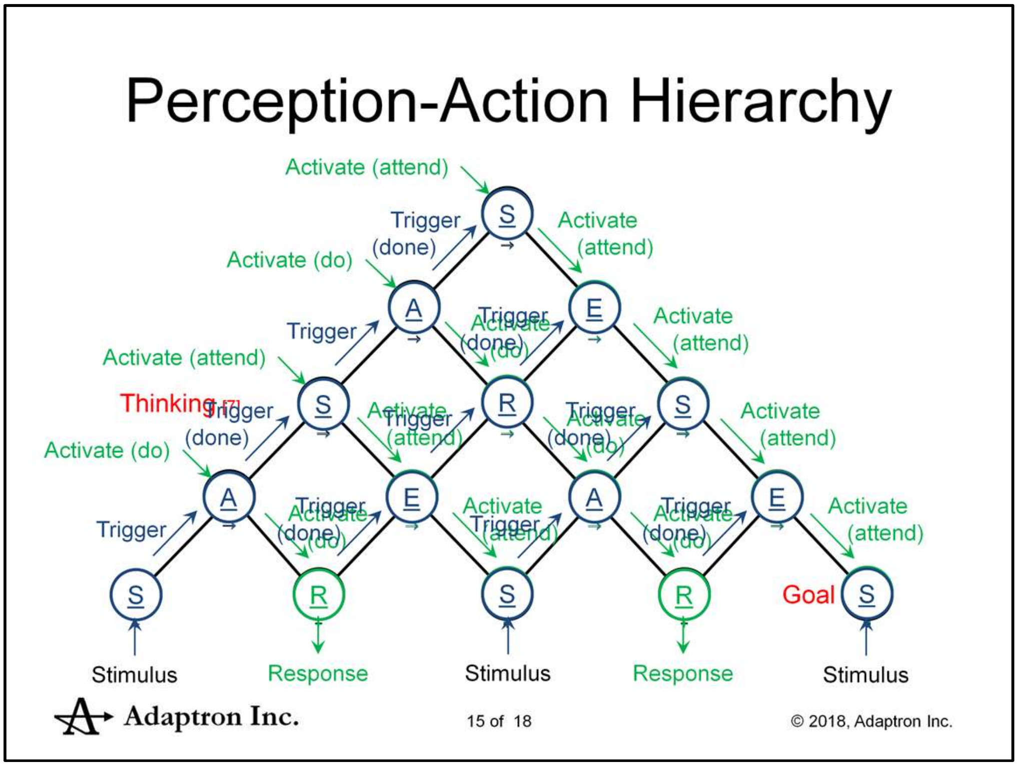
A stimulus sequence like this captures the information that is found in the forward model in motor control in neural networks and neuroscience. That is: “Given a stimulus and a response you can expect the next stimulus”. This structure also represents the information that is found in the Backward or Inverse model in motor control. The inverse model says: “Given the current stimulus and a desired future stimulus then perform the response”.

It is possible for the Response binon to be a “do nothing” response. Then no action is performed. An example of such a stimulus sequence is the process of listening to music. An example that would include a response while listening to music would be dancing.



Combining the previous expectation example and a new reach action binon produces a response sequence at the top. Along the bottom row of spatial binons you can see the Response-Stimulus-Response sequence. It starts with looking at the object and ends with moving the to the toy.

This response sequence is now represented as a temporal response binon at the top of the hierarchy. Just like the stimulus sequence on the previous slide this response sequence can now be reused as the trigger source in more complicated expectation control sequences.



[This is an animated slide showing the flow of activation and triggering as it flows through a more complicated stimulus sequence. It also shows where thinking gets involved.]

Given that this P-A hierarchy is already learnt, the process starts when the stimulus at the bottom left attracts attention.

Thinking about this behavioural P-A hierarchy results in the identification of a goal stimulus at the bottom right that is worth achieving.

As a result of the hierarchy is then activated up the left side.

The wave of activation flows from left to right and from bottom to top as the first response is done and the second spatial stimulus is experienced.

If the second spatial stimulus is not recognized the second response will not be done and the goal will not be reached.

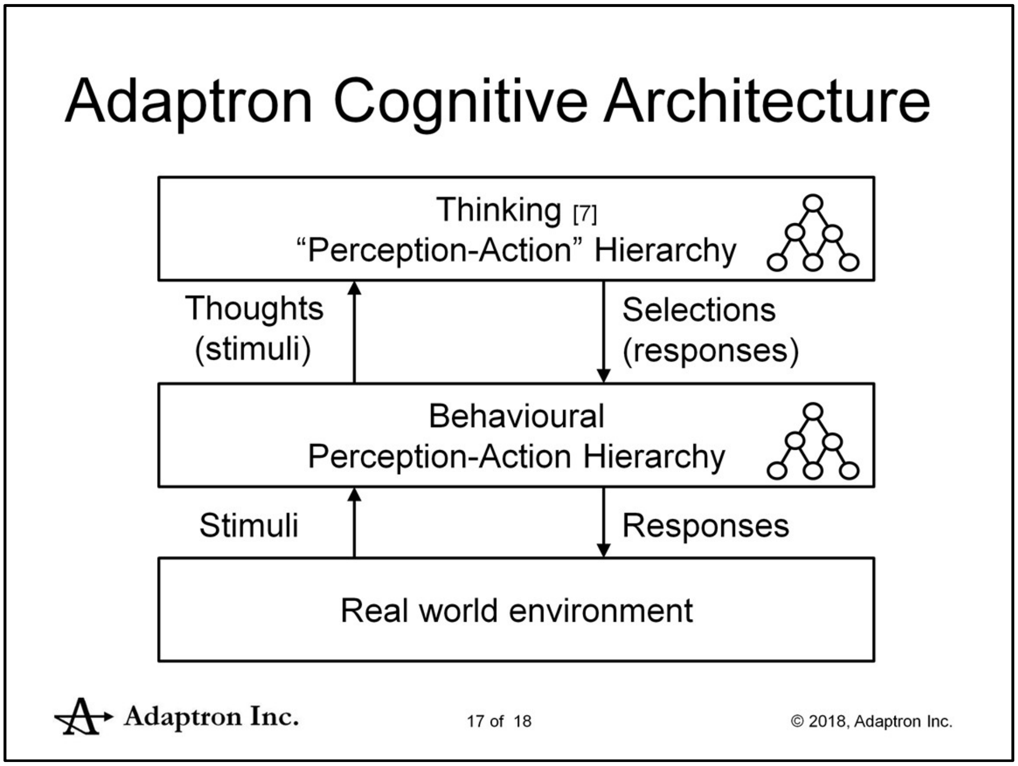
[The video of this presentation, which includes the animation of this slide, is available at: http://www.adaptroninc.com/BasicPage/presentations-and-slides]

Simultaneously Active Binons

- Many activated action binons [6]
- Each waiting for its trigger
- While walking down the hallway
  - Action binons are activated waiting for
    - An obstacle to be seen
    - A closed door to be encountered
  - Triggered when the stimulus occurs

Multiple action binons can be activated simultaneously (in parallel). Each one waiting for its trigger source binon to be recognized. This allows Adaptron to perform complex tasks while being ready to handle unexpected events.

For example, walking down a hallway while avoiding obstacles and opening closed doors.. Walking is a stepping action that repeats the same stimulus-response sequence. Simultaneously the “avoid obstacle” and “open closed door” action binons can be activated but not yet triggered. They will start when and if their trigger stimulus is encountered.



In the Adaptron Cognitive Architecture there are two perception-action hierarchies.

The behavioural one learns to act in the real world. It contains memories of its experiences. It is a model of reality as experienced.

The thinking perception-action hierarchy that sits on top uses the memories in the behavioural one as its environment. The thinking hierarchy’s stimuli are thoughts which result from recalling memories from the behavioural hierarchy. And the thinking hierarchy’s responses are selections of either associated memories (recollections) or actions to perform from the behavioural hierarchy.

The thinking hierarchy contains memories of these thoughts and selections just like the behavioural hierarchy contains memories of stimuli and responses. And it learns to think based on the same learning principle of the behavioural hierarchy, that is babbling (reusing), practicing and automaticity.

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.

[5] http://www.adaptroninc.com/sites/default/files/inline-files/Learning%20V1.pdf

[6] http://www.adaptroninc.com/sites/default/files/inline-files/Action%20Learning%20V1_0.pdf

[7] http://www.adaptroninc.com/sites/default/files/inline-files/Thinking%20V1.pdf