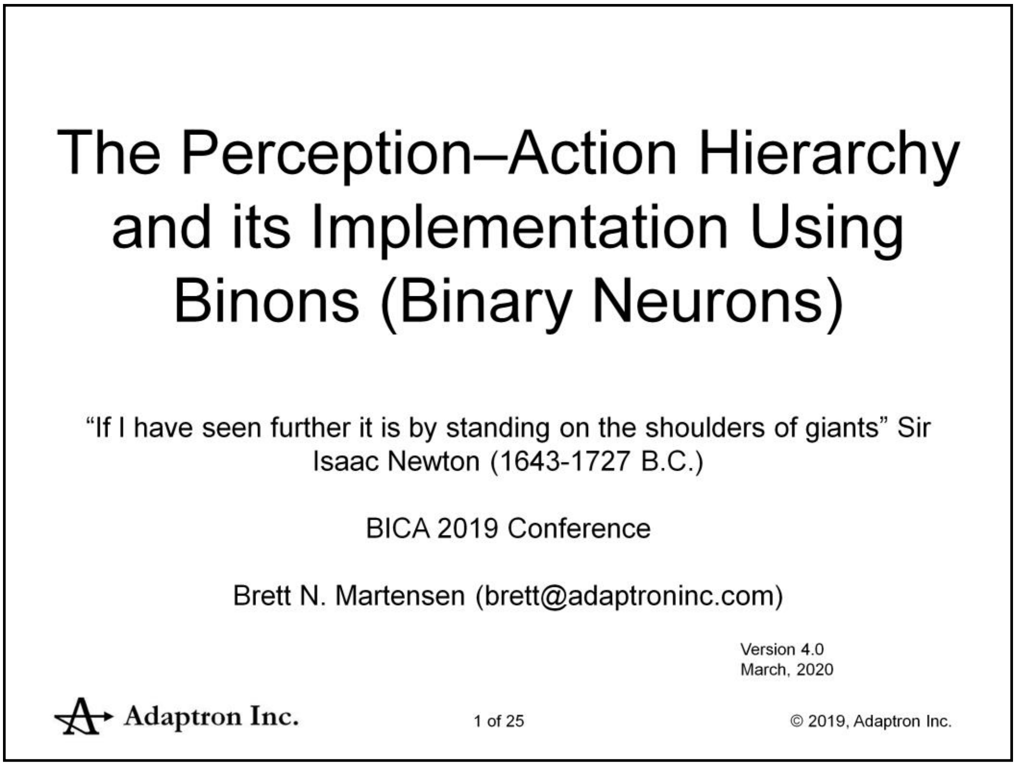


Abstract:

The perception–action hierarchy contains a model of the environment as experienced based on what has been recognized and done. Binons (binary neurons) can be used to represent and implement this hierarchy. Binons are simple deterministic artificial neural nodes that represent relationships. They have two source nodes and are reused by zero or more target nodes. Binons are general purpose components that interact in an object-oriented fashion. The two types of binons are spatial and temporal. Spatial binons represent simultaneously occurring patterns of percepts and actions. Temporal binons represent sequential patterns of percepts and actions. Two kinds of temporal binons are used to learn and control behaviour. They are the action and expectation control binons. They are equivalent to command neurons in neuroscience, production rules in cognitive architectures, or the forward model in motor control when combined. Learning takes place in the three stages of babbling, practicing and automaticity. The resulting hierarchy is a transparent, compositional, unsupervised, continuously growing, deep learning artificial neural network. The hierarchy is part of the Adaptron cognitive architecture.

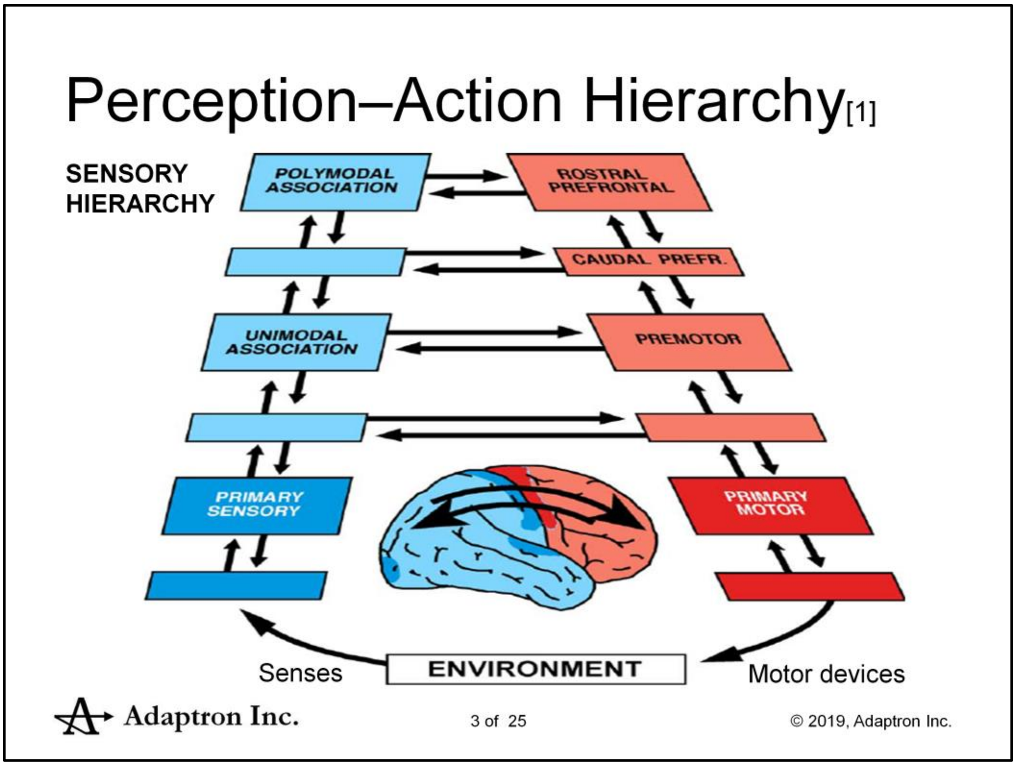
A lot more detail can be found in other presentations mentioned in the references. A lot of these concepts are not new. What I have done is aggregate the ideas that too-many-to-mention brilliant scientists before me have invented and published in the areas of psychology, cognitive science, artificial intelligence, neuroscience, psychophysics and robotics.

Contents

- The Perception–Action Hierarchy
- Binons (<u>Bin</u>ary Neur<u>ons</u>)
  - Spatial and Temporal
  - Action and Expectation control binons
- Simultaneously active binons
- Adaptron Cognitive Architecture
- Robot simulation results
- References

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 [1]. [Read more about it on Wikipedia at: https://en.wikipedia.org/wiki/Motor_cognition#Perception-action_coupling or https://en.wikipedia.org/wiki/Sensory-motor_coupling]. I call it a Behavioural Perception-Action 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. This produces percepts which are combined into more complex multi-modal percepts.

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 percepts with actions. These are the action and expectation habits described in this presentation.

Perception–Action Hierarchy

- Actions – sensory to motor associations
  - Production rules
  - **If** recognize a percept **Then** do an action
  - Command Neurons [2]
- Expectations – motor to sensory associations
  - **If** done an action **Then** expect a percept
  - Part of the forward model in motor control [3][4]

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

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

= **If** recognize a percept **then** do an action

= Command Neurons in neuroscience. [2]

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

= **If** done an action **then** expect a percept

= Part of the forward model in motor control [3] [4] in neural networks and neuroscience.

The complete forward model says: “Given a percept and an action you can expect the next percept”.

Properties of the P–A Hierarchy

- Reuses learnt percepts and actions
  - Compositional structure
  - Combines more general simple lower level properties/features/acts
  - Produces more specific complex higher-level representations/concepts/actions
- It learns bottom-up
  - Babbling, practicing, automaticity

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

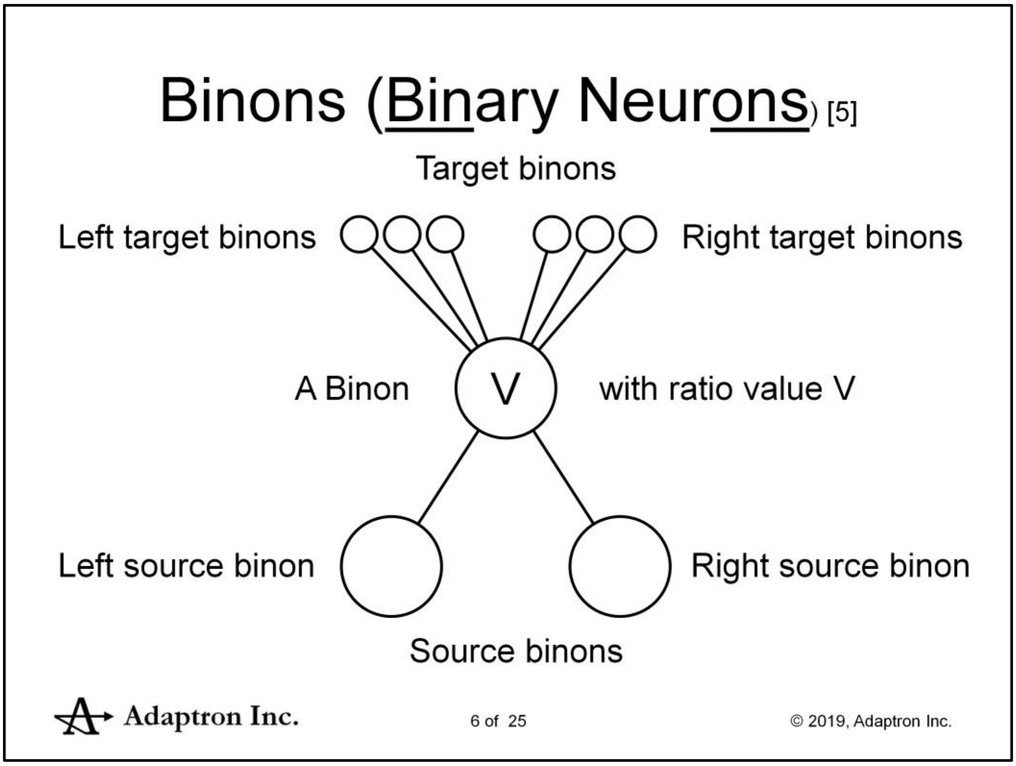
A mature P-A hierarchy takes years to learn. There are three stages to learning; babbling, practicing and automaticity.

Babies use babbling to perform random motor and speech acts. 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.



A binon is a neural node in a network [5]. 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 actions. They are reused by multiple target binons.

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

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

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

The Binon

- Spatial and temporal binons
  - Parallel recognition and action [+]
  - Sequential recognition 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]

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 percepts and actions.

However, the growth rate is gradual and controlled – see the Perceptra paper [5].

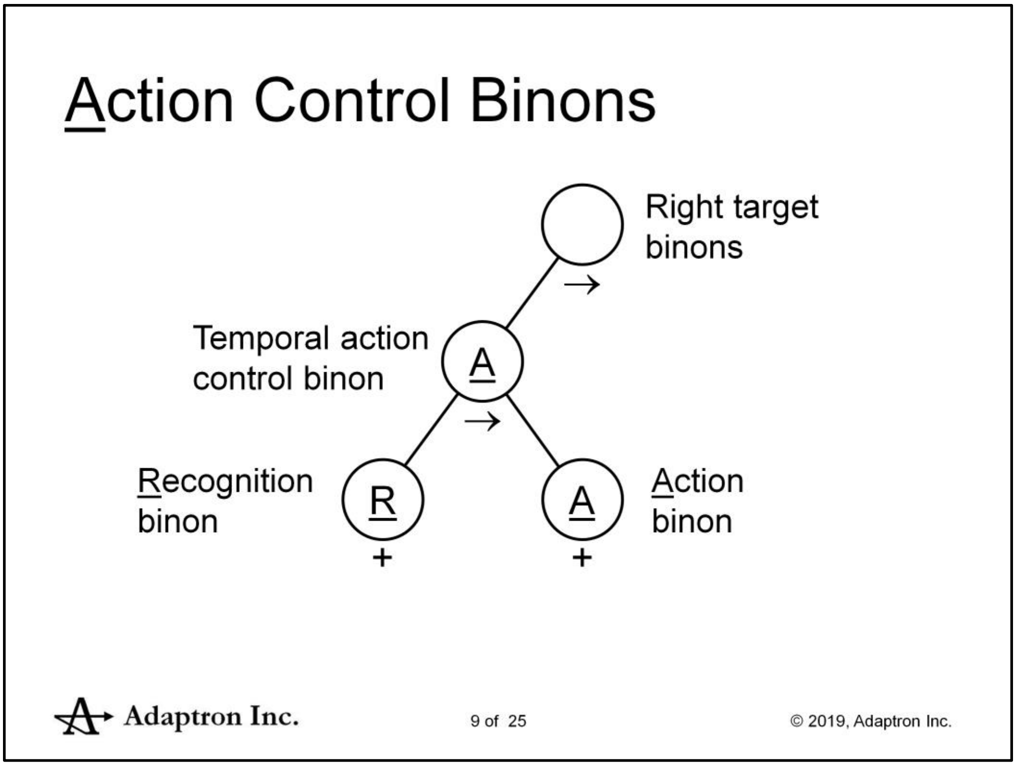
Roles Played by Binons

- Recognition and Action spatial binons

R
+
Recognition binon

A
+
Action binon

The underlined letter in a binon (R and A) indicates the role a binon is playing.



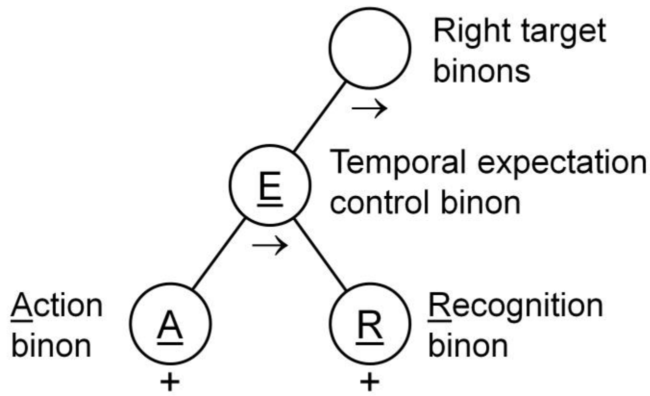
There are two types of temporal control binon: the action control and expectation control binon. The underlined letters in the binons (R, A and E) indicate the role they play in the process. The process is equivalent to the If recognize a percept then do an action production rule.

A Recognition binon represents and recognizes a percept from the environment (via the senses) or a simultaneous combination of percepts to represent concepts and objects.

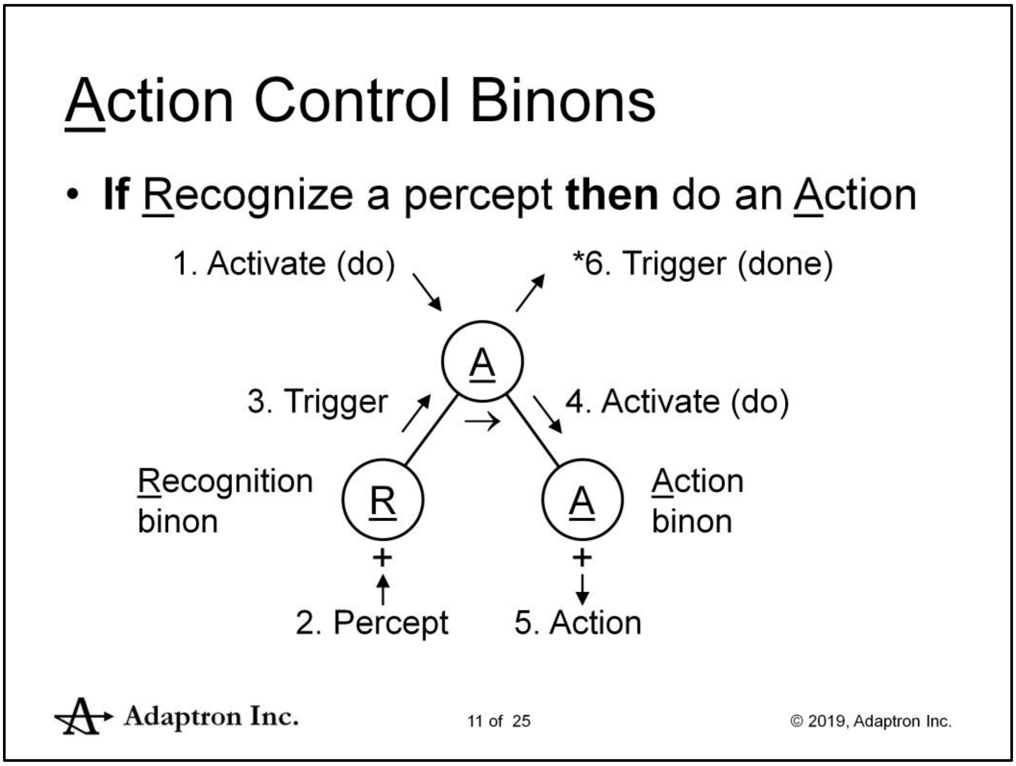
A spatial Action binon represents and activates a simple or complex action in the environment (via action devices).

A temporal Action control binon represents and controls what action to perform when a percept is recognized.

Expectation Control Binons



A temporal Expectation binon represents and controls what percept to expect after an action has been performed.



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

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

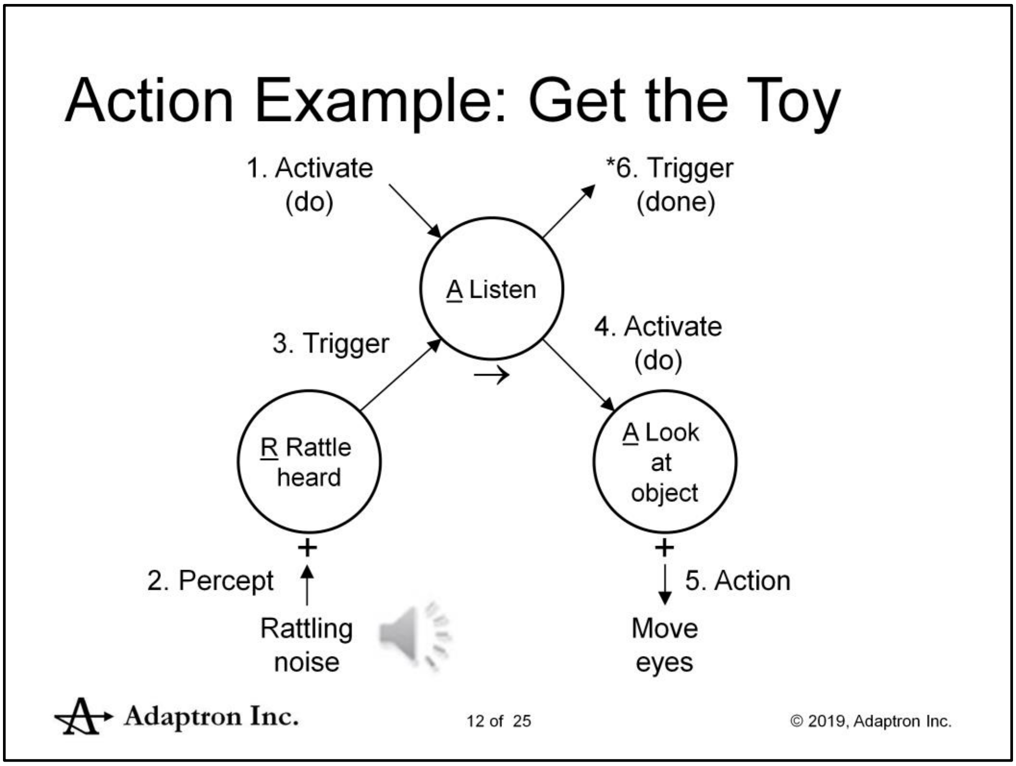
“After I’ve been activated and have recognized the trigger I was expecting, I can tell you (the following binons) to start doing or continue doing your job”.

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 left source to fire. Then it can fire all its out going links – the right source binon and all the right targets. Nothing will happen if the temporal binon is activated but the left source does not occur. Similarly, nothing more will happen if the left 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.

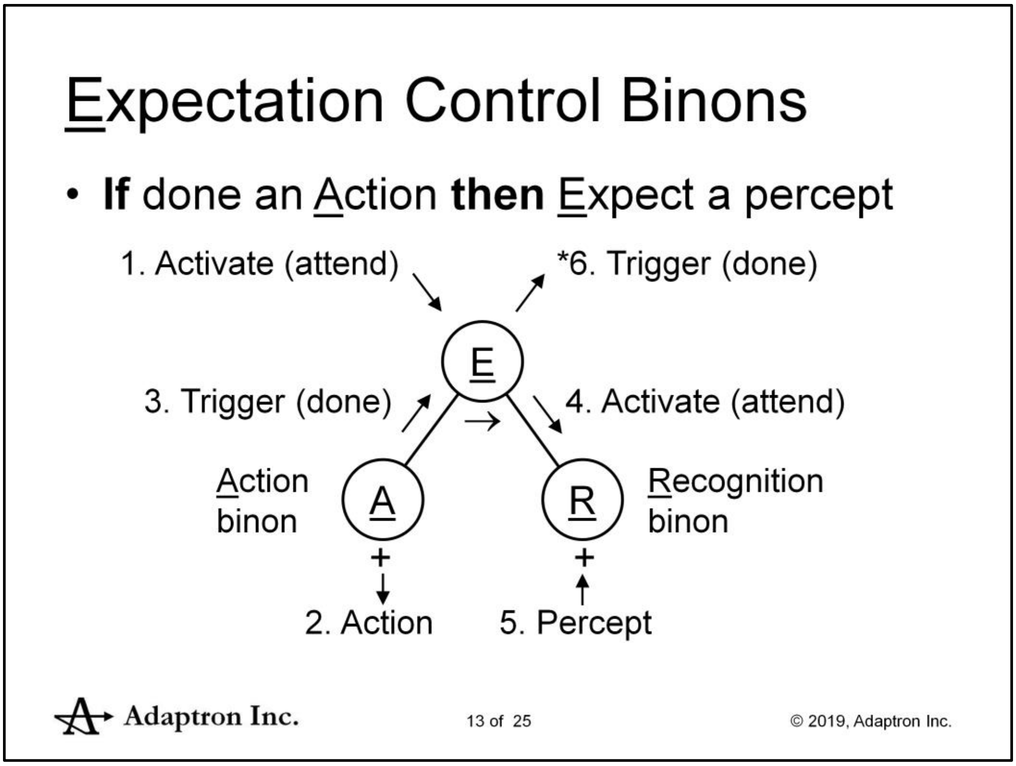
In psychology the Activate(do) is the same concept as preparatory motor set. And the Activate(attend) is the same concept as perceptual set.

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



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

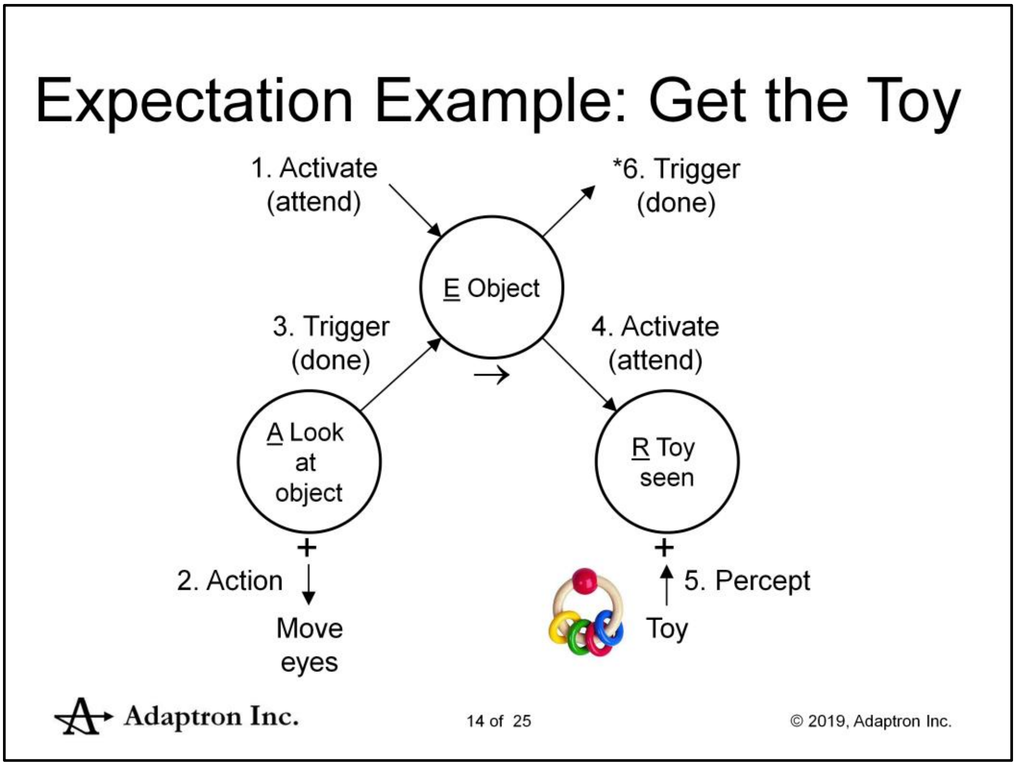
This is the very first action habit in the task. The baby is actively listening. It hears a rattling noise and it looks for the object by moving its eyes.



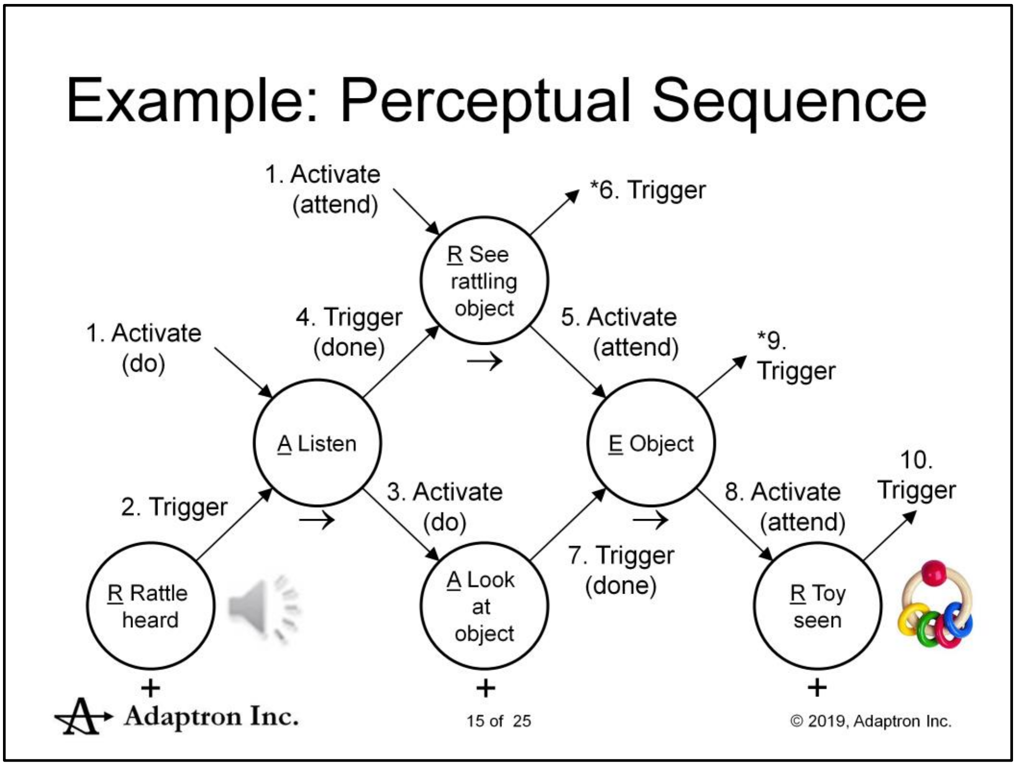
After performing an action, you expect some resulting percept. This interaction diagram captures the order in which this expectation control process takes place. It is equivalent to the If done an action then expect a percept production rule.

The Expectation binon represents and controls what percept to expect when an action is performed.

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



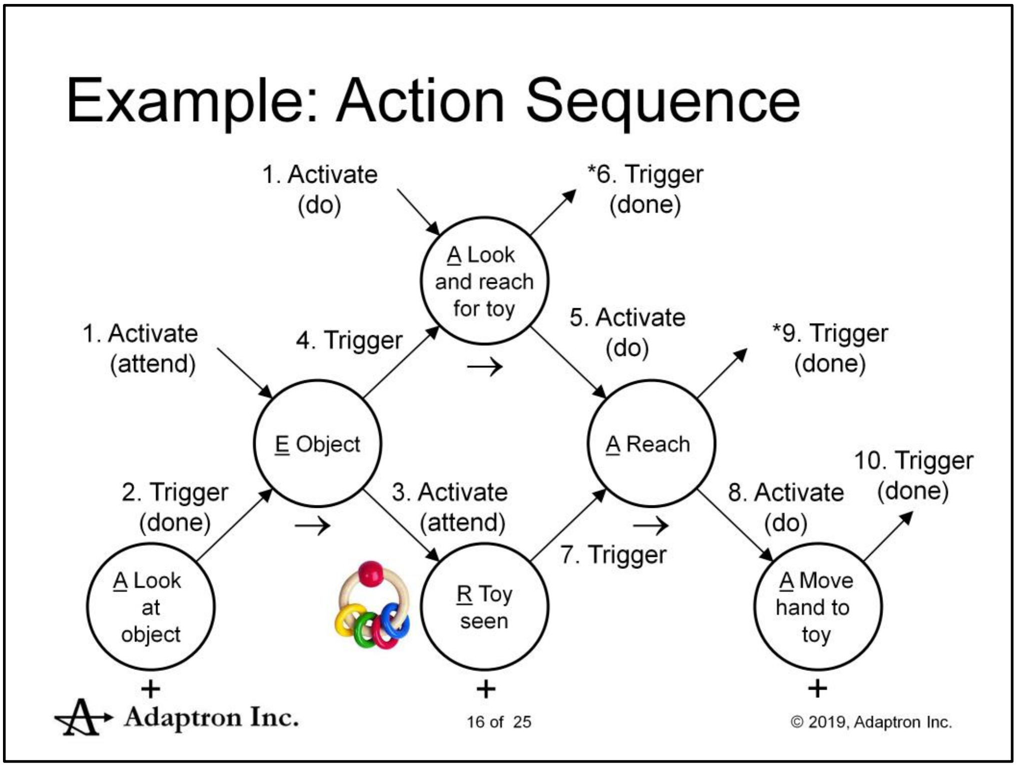
As an example; once the baby's eyes have moved to where the noise originated it is expecting to see the rattling object. What it sees is a toy.



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

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

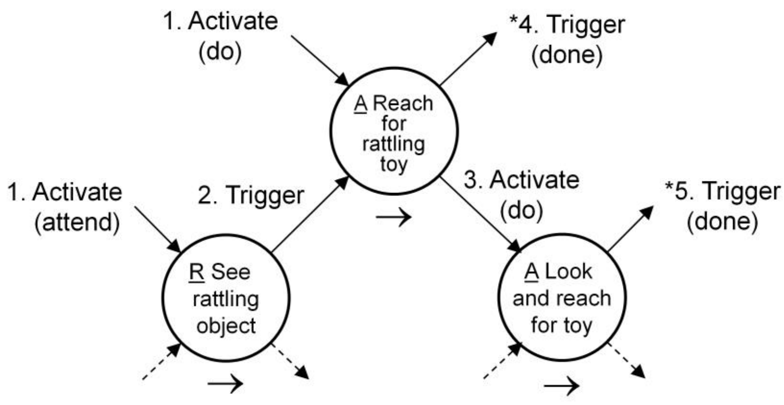
A perceptual sequence like this captures the information that is found in the forward model in motor control in neural networks and neuroscience. That is: "Given a percept and an action you can expect the next percept". This structure also represents the information that is found in the Backward or Inverse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



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

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

Higher-level Combination



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The perceptual sequence (R See rattling object) and action sequence (A Look and reach for toy) can now be reused in a more complicated action control sequence as illustrated. In Adaptron, hierarchies of control binons like these continue to grow as they are learnt, practiced and reused.

Simultaneously Active Binons

- Many activated action control binons
- Each waiting for its trigger
- While walking down the hallway
  - Action control binons are activated waiting for
    - An obstacle to be seen
    - A closed door to be encountered
  - Triggered when the percept is recognized

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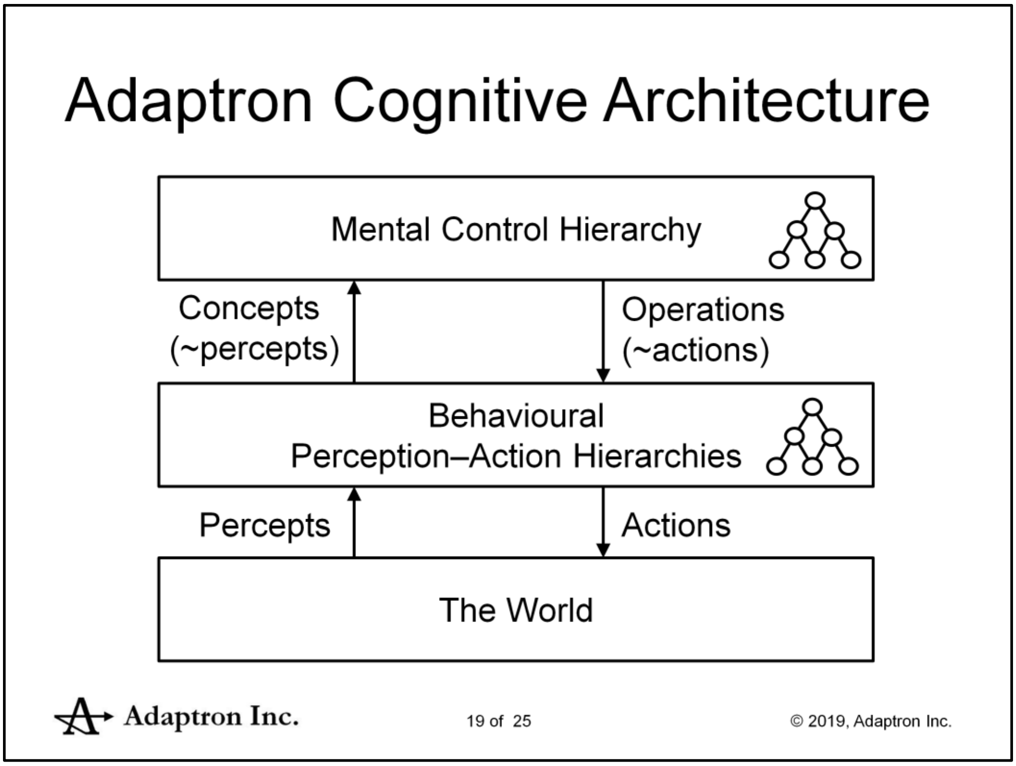
Multiple action control binons can be activated simultaneously (in parallel). Each one waiting for its left source binon to be recognized. This allows Adaptron to perform complex tasks while being ready to handle unexpected events.

For example, walking down a hallway while avoiding obstacles and opening closed doors. Walking is a stepping action that repeats the same percept-action 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 percept is encountered.

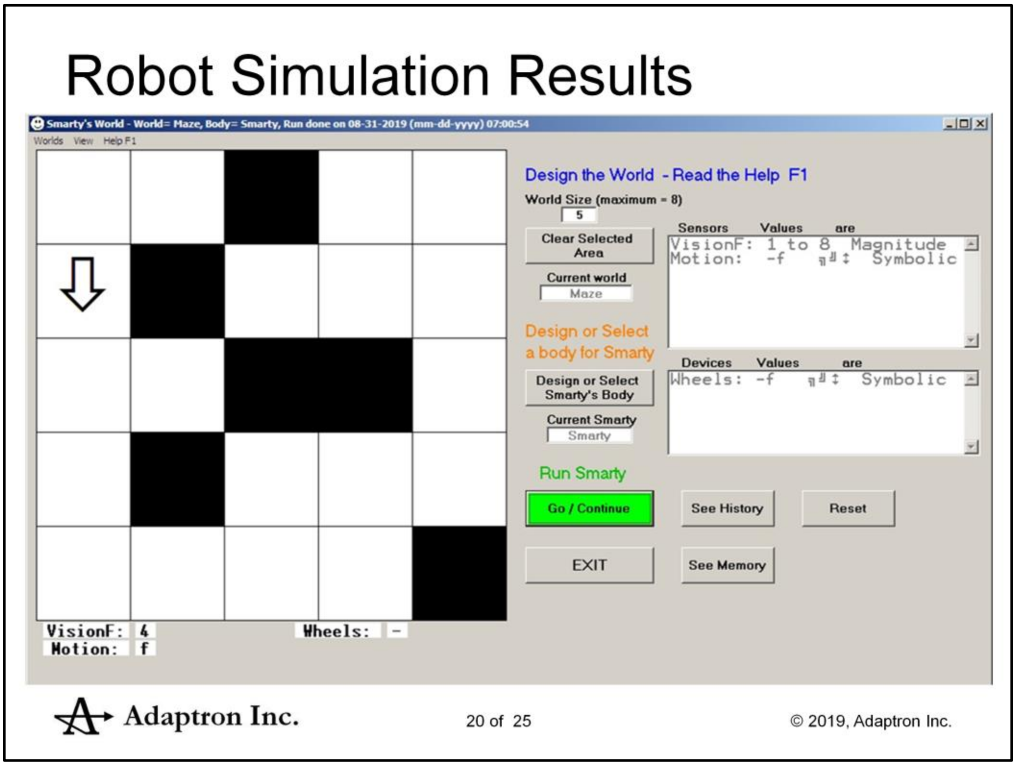


In the Adaptron Cognitive Architecture there are two perception-action hierarchies. It's a dual process theory architecture (e.g. system1 and system 2) [6].

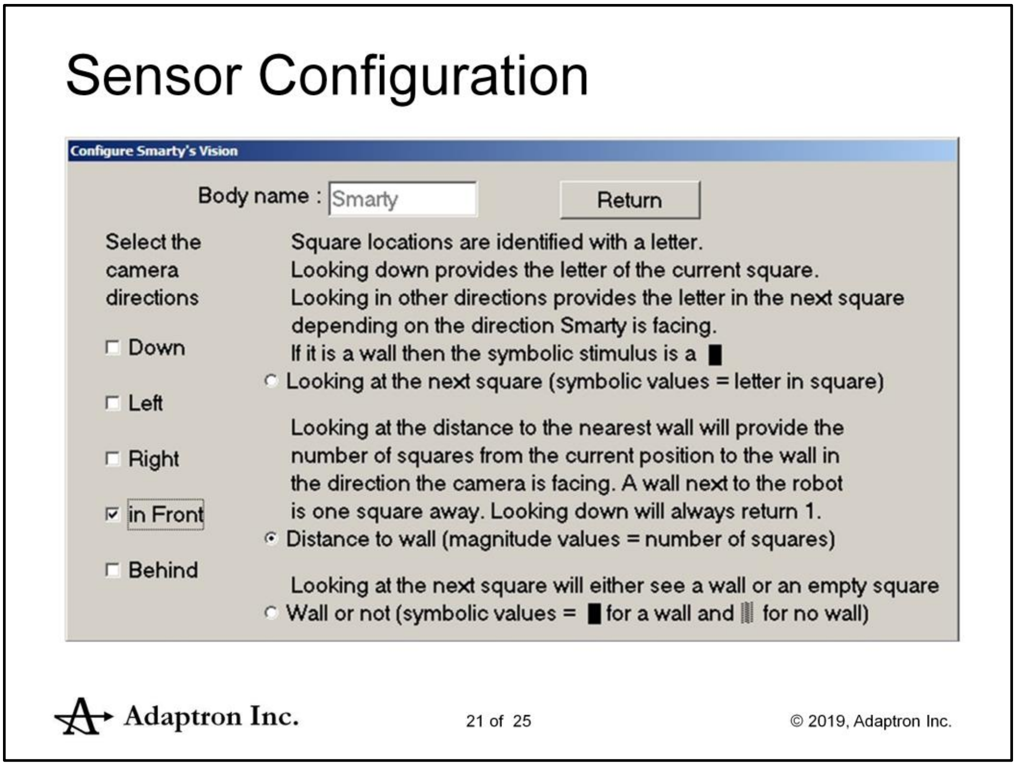
The behavioural one learns to act in the real world. It contains memories of its experiences. It is a model of reality as experienced.

The mental abstraction-concentration hierarchy that sits on top uses the memories in the behavioural one as its environment. The thinking hierarchy's percepts are concepts which result from recalling memories from the behavioural hierarchy. And the thinking hierarchy's actions are mental operations of either associated memories (recollections) or actions to perform from the behavioural hierarchy.

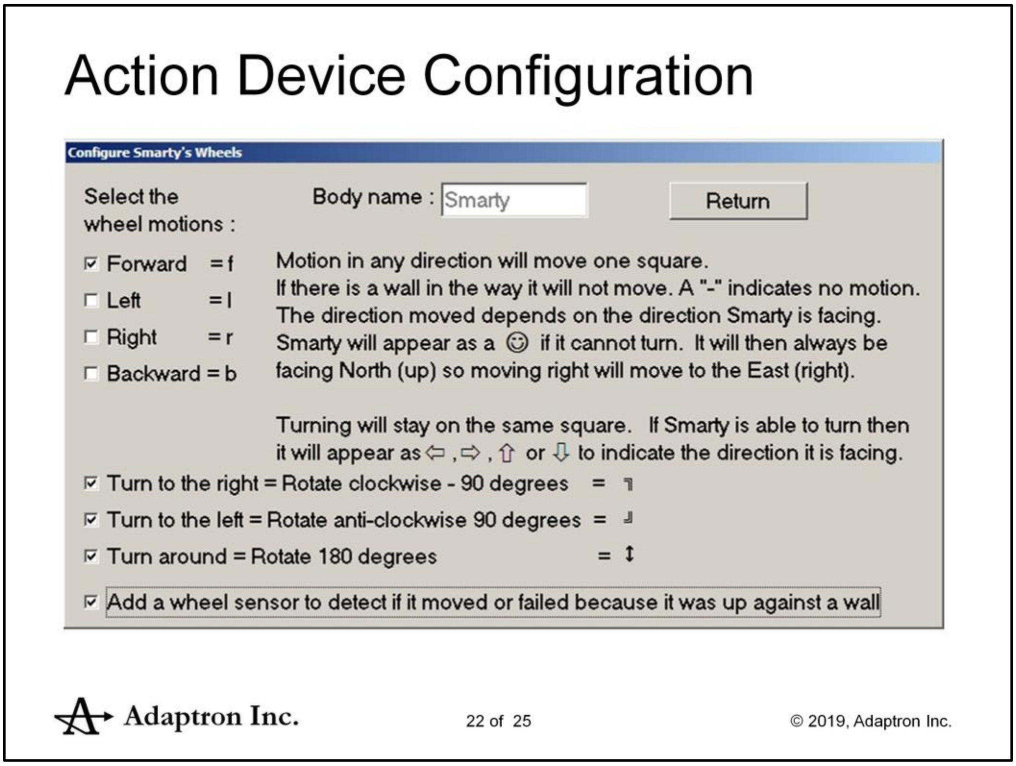
The thinking hierarchy contains memories of these thoughts and selections just like the behavioural hierarchy contains memories of percepts and actions. And it learns to think based on the same learning principle of the behavioural hierarchy, that is babbling (reusing), practicing and automaticity.



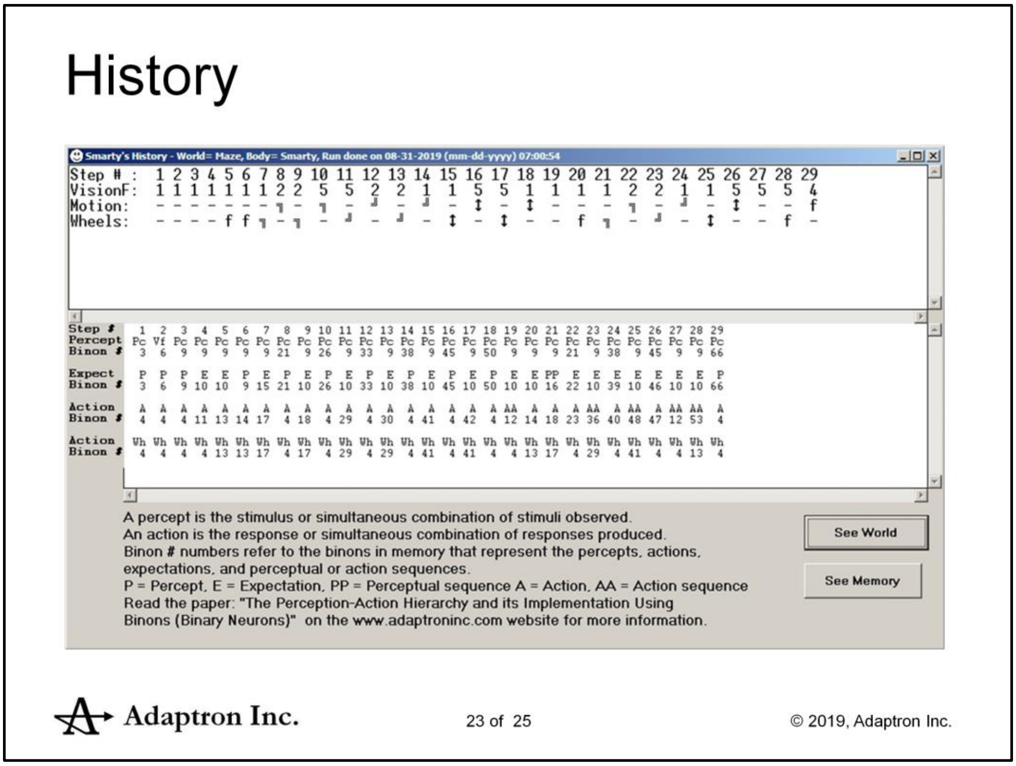
The perception-action hierarchy implemented using action and expectation binons has been successfully implemented in a simulated robot called “Smarty”. It explores any designed maze world given a configuration of sensors and wheels. As illustrated, the simulation allows for a world to be designed on a grid of squares up to 8x8 in size. Each square is represented by a letter of the alphabet for symbolic stimulus recognition.



The robot body can be configured with sensors and action devices (wheels) as shown. Sensors are cameras and a motion detector. Cameras can be configured to see a letter in a square, the distance to a block (non-symbolic stimulus) or an adjacent block or empty square.



The wheels can be configured to move one square in any direction or rotate at the current position. A proprioceptive wheel sensor can be enabled to detect the motion of the robot. If the robot tries to move forward into a block the action is shown as an “f” but the motion sensor will indicate no motion as a “-“. In this example the vision sensor values are non-symbolic magnitudes.



The results of the robot performing 29 “Go / Continue” steps is illustrated. It shows the robot starting to explore the given maze world. Note that at step 20 the robot tries to move forwards but did not move. The motion percept in step 21 is a “-” indicating no motion was recognized.

Memory

The display of some of the binons in memory and the processing of the most recent step are shown.

References

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

[2] Ewert, J. 2003. Command Neurons and Command Systems. In Arbib, M. A. (Ed.), *The Handbook of Brain Theory and Neural Networks – 2nd ed*. Cambridge, Massachusetts: MIT Press. 233-238.

[3] Grush, R. 2004. The emulation theory of representation: Motor control, imagery, and perception. *Behavioral and Brain Sciences* Vol. 27, pp 377–442

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

[5] 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.

[6] Gawronski, B. and Creighton, L. A. 2013. Dual Process Theories. In Carlston, D. E. (Ed.) *The Oxford handbook of social cognition*. New York, NY: Oxford University Press. Ch. 14:282-312

Many additional references are available in the paper.