Senses, Sensors and Action Devices

"Nothing is in the mind which was not first in the senses."
Aristotle (384-322 B.C.)

Version 1.0
7th March 2018

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Senses, Sensors and Action devices are the body's interface components that allow the brain to interact with the environment.

Contents

- Grounded and embodied behaviour
- Senses – external and internal
- Sensor characteristics
  - – Dependency and type of measurements
- Sense of time
- Just noticeable difference
- Action devices and responses

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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.

If you are well versed in these subjects skip this presentation and

go on to those that describe the principle of operation of Adaptron, starting with the Binons presentation.

Grounded Behaviour

- Animals and robots need to be
  - Situated in an environment
    - In touch with reality
      - via senses
    - Performing action in their environment
      - via action devices
  - Embodied
    - A system of components
      - Sensors and action devices
      - Supported in an infrastructure
        - » The body

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These characteristics of Senses and Action Devices may seem obvious but

it is important to always keep them in mind when trying to develop grounded and embodied AGI (Artificial General Intelligence).

Human Senses – External

- Eyes – vision (light)
  - Colour, brightness, distance
- Ears – hearing (sound)
  - Volume, pitch (frequency), direction
- Skin – touch (mechanical)
  - Pressure, temperature, stretch
- Tongue – taste (chemical)
  - Salt, sour, bitter, sweet, umami
- Nose – smell (chemical)
  - Odours

These are the five normally understood human external senses.

External because they measure the environment in which we live.

All sensors measure some form of energy – light, sound, mechanical, temperature and chemical.

Each sense may measure several properties.

Internal Senses

- Inner ear (gravity, balance)
  - Acceleration, roll, pitch, yaw, orientation
- Muscles, tendons and joints (motion)
  - Tension, angle/position
- Other senses to detect
  - Thirst
  - Hunger
  - Fatigue
  - Pain
- Time

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But there are internal senses that detect the state of the body (not necessarily a type of energy).

And don’t forget about the sense of time.

Muscle spindles are sensors that detect the length and rate of stretch of the muscle.

The muscles also contain Golgi tendon organs (GTOs), which are attached to the tendons of muscle and respond

to increased tension in the tendon.

Robotic Senses

- Camera (light, infrared/heat, ultraviolet)
- Antenna (radio waves)
- Laser range finder (distance)
- Microphone (sound, ultra-sound)
- Thermometer (temperature)
- Compass and GPS (direction & location)
- Pressure sensors (pressure, stress, tension)
- Anemometer (wind speed)
- Radar dish / gun (distance, speed & altitude)
- Tachometer (angular velocity)
- Gyroscope (roll, pitch and yaw)
- Etc.

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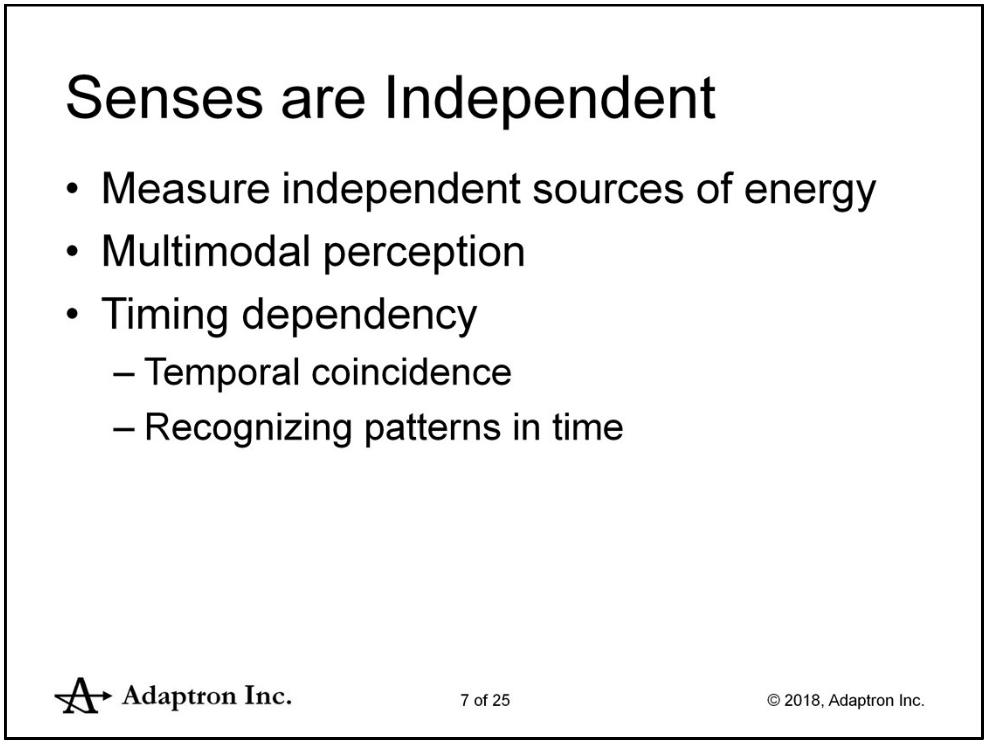
But when dealing with robots there are many more things that can be measured.

Many out of the range of human ability, such as ultrasound, radar and even X-Rays.

And internal senses required for rotation (roll, pitch & yaw – a Gyroscope), energy (battery) level,

wear on joints or axles, strain on body parts, hydraulic fluid pressure, tire air pressure etc.



There is no physical dependency between senses.

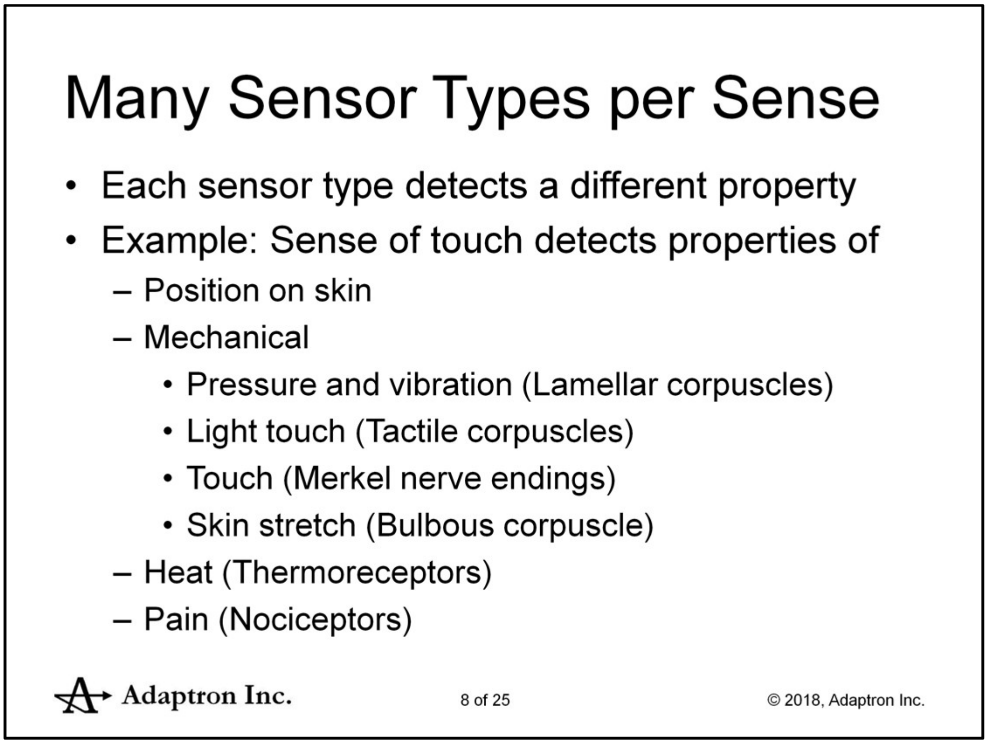
It is only our brains that can detect the dependency and

that is usually done through the detection of coincidence

– two or more things (events) happen at the same time or one after the other (next slide).

You see the door close and hear it close.

This is what is called multimodal perception.



Another example: Vision detects colour and brightness.

These are two independent properties.

Sensor Type Characteristics

- Sensor types are independent
  - Measure independent properties
    - Pressure and temperature for sense of touch
    - Colour and brightness in vision
  - Timing dependency
    - Recognizing patterns in time

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The sensor types in any given sense are independent because they each measure a different property.

Just like independent senses, any dependency is determined by our brains because of temporal coincidence.

Sensor Type Characteristics

- Position dependency
  - – Next to each other (adjacent)
- Spatial coincidence
  - – Recognizing things in space
    - Sounds
    - Shapes

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Rod and Cone cells in the retina are beside each other and form a two dimensional array and thus are spatially dependent sensors.

Hair cells in hearing are adjacent. They measure volume.

Their position in the cochlea represents the frequency / pitch.

Sensor Type Characteristics

- Independent sensors have:
  - No spatial relationship to each other
    - Muscle tensions (limbs, tongue and diaphragm)
    - Rotational positions of wheels on a car
- Temporal coincidence
  - Recognizing patterns in time

The tongue is independent of limbs and thus so are their touch sensors.

Temporal coincidence is necessary to recognize anything.

We find independent sensors in robots.

The rotational positions of wheels on a car are independent of each other.

If a robot is embodied in an intersection to control the lights and pedestrian crossings the pressure pads that cars go over are all independent.

Example: Hearing

- An array of sensors (hair cells)
  - Measure the volume of sound
  - For a given pitch / frequency
  - Over time
- Two ears provide direction information

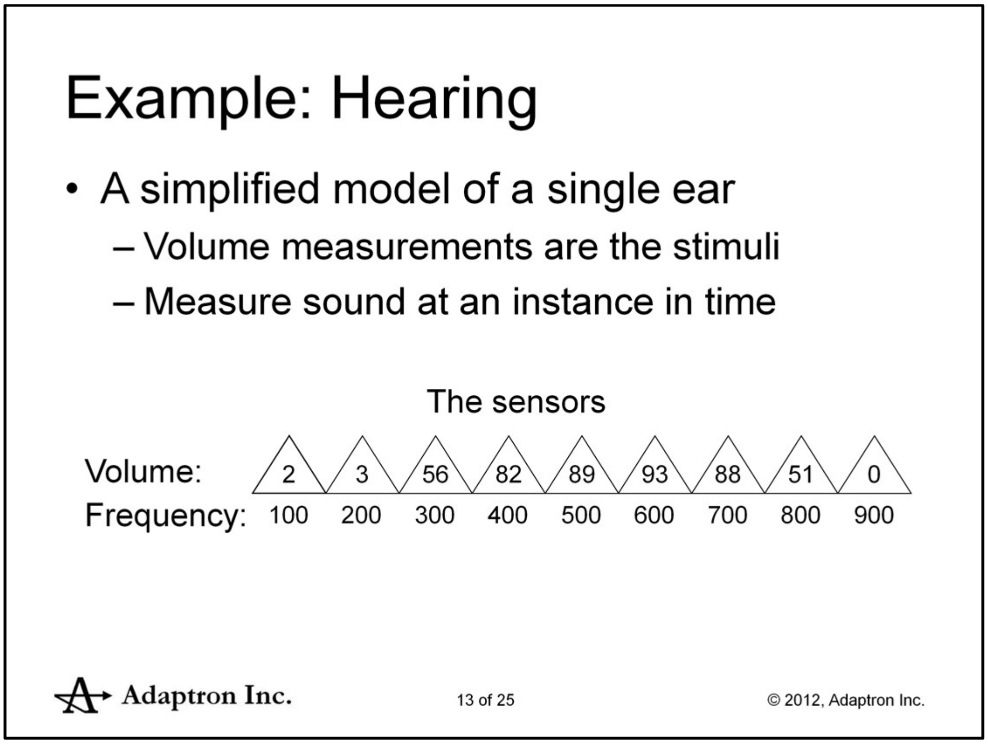
Let’s investigate a simpler sense.

Even though hearing is complex it is much simpler than vision and touch.

It only measures one property and that is loudness or volume in physics.

Each volume measured is for a different frequency or pitch in music.

The hair cells are the sensors and each one is tuned to a specific frequency based on its place in the cochlea.



This is much simpler than reality but we must model at the simplest level first before adding complexity because the devil is in the detail.

Simpler than reality because the frequency resolution is not uniform over the entire frequency range.

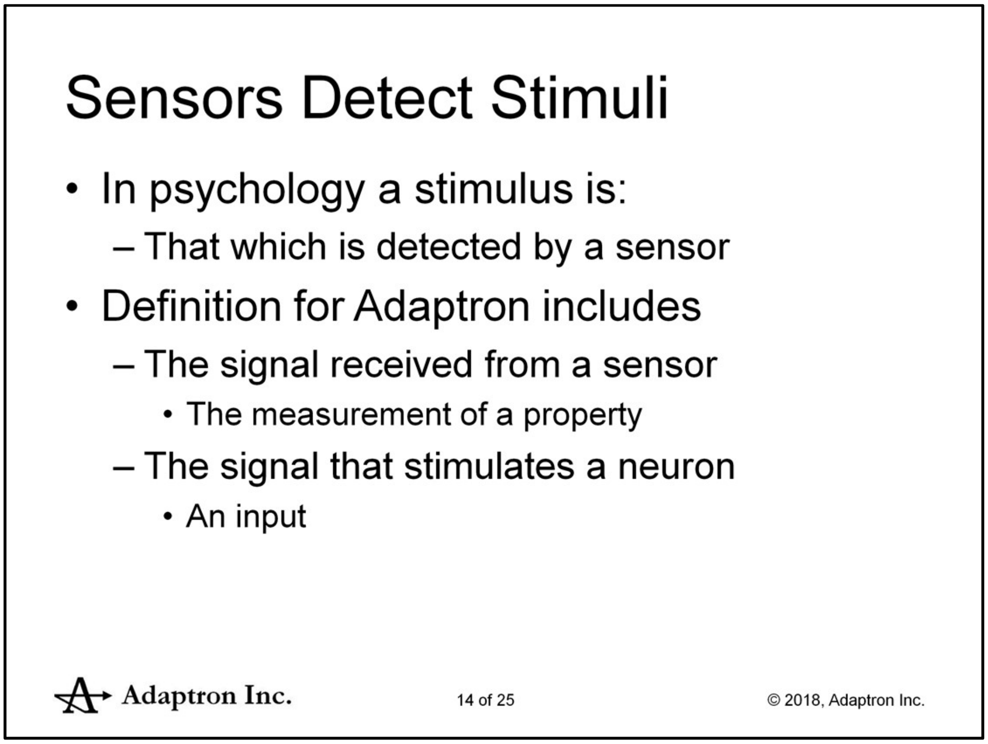
Timbre is a particular pattern of volumes (loudness) at certain frequencies (pitch) that occur simultaneously.

It is usually associated with musical instruments that generate different volumes at certain harmonic frequencies.

It is kind of like playing a chord on a piano but instead of using strings a pure sine wave sound frequency is generated for each key.

A real piano string however has its own timbre so a real chord is quite complex.

All the examples like this that I provide in these presentations are based on a one dimensional array of sensors.

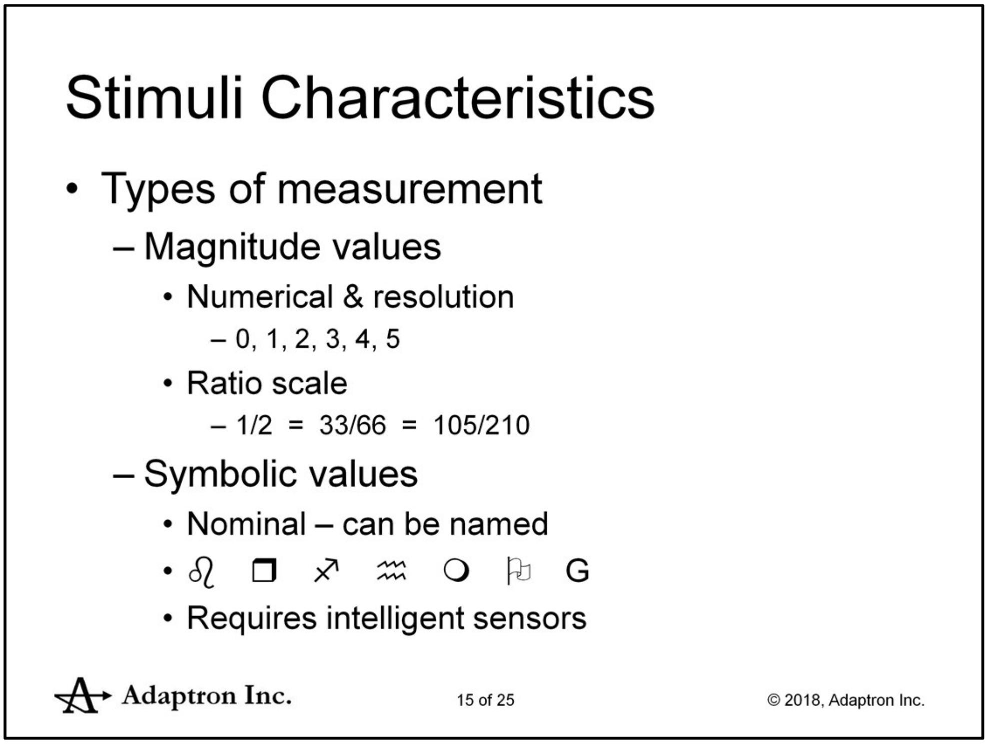


A sensor measures the intensity of the property based on the sensor's type.

The information the sensor measures is sent as a signal into the nervous system.

For Adaptron purposes this signal is a stimulus. In computer terminology – an input.

I also use the term stimulus for the signal that is input to any neuron when it is stimulated by another neuron.



The type of stimulus depends on the type of sensor that measures the property. I have, in the past, been using the term Graduated sensors to mean Magnitude sensors. I realized that Graduated could be confused with Interval scale – see below.

Magnitude measurements have a zero that corresponds to nothing /zero in the physical world and ratio arithmetic can be performed on them.

Magnitude measurements are always positive. There is a resolution to the values produced by the sensors such that no in-between values can be detected. This is officially called a ratio scale.

Nominal scale (symbolic) allows names (or numbers) to be assigned to symbols for representation purposes but does not give them any particular order. No arithmetic can be performed with symbolic values.

For a sensor to produce a symbolic stimulus it needs the intelligence to recognize them. Other levels of measurement or scale of measure include ordinal and interval.

An example of an Ordinal scale would be the alphabet. The letters are in a particular order but no arithmetic can be done on them. They are interdependent because they are in order.

Interval scale assigns a numeric measure to something with equal distance between the values such as temperatures (in Celsius but not Kelvin), positions or dates. You can perform a ratio calculation such as one temperature is twice as hot as another in Kelvin but not in Celsius because of the arbitrary location of zero degrees Celsius.

Dependent / adjacent sensors can be given a position which is an interval scale. But the distance between two positions (size or width) is a ratio scale

Sense of Time[1]

- Events are adjacent in time
  - Sequential and Dependent
  - Recognizing temporal patterns
- Date and time are interval measurements
- Duration is a ratio scale
  - The time between two events
  - Temporal recognition
    - Speech
    - Motion

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Somewhere in our nervous system we measure the duration between events – two or more things (events) happen one after the other.

You hear the door squeak and then hear it close.

Just Noticeable Difference (JND)

- Weber’s Law [2]
- 100 grams versus 101 grams
  - NOT noticeable
- 100 grams versus 110 grams
  - IS noticeable

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JND is part of the science of Psychophysics. JND is the resolution of the sensors. How good are they at recognizing the difference between two values.

The resolution changes based on the value of the measurement.

Examples: humans require a 4.8% difference in loudness to detect a change but a 7.9% difference in brightness is necessary. (These are different from the numbers below!)

Ernst Weber (1834/1978) measured JNDs of roughly 8% to 10% in experiments involving active lifting of 32 oz. weights. A 1% difference in line length. Musical pitch a 0.6% JND. Jones (1989), in a force matching experiment about the elbow, found a JND ranging between 5% and 9%.

Pang, Tan and Durlach (1991) report a JND that lies between 5% and 10% for pinching motions between finger and thumb with a constant resisting force.

This JND was found to be relatively constant over a range of different base force values between 2.5 and 10 Newtons.

Some interesting human-sense JNDs (Just Noticeable Differences) are : Pitch: 1/333 (0.3%), Brightness: 1/60 (1.8%), Lifted Weights: 1/50 (2%), Loudness: 1/10 (10%), Pressure on skin: 1/7 (14%), Taste: 1/5 (20%) - Reference : http://www.richardbrice.net/webers_law.htm

Notice how our sensitivity to pitch is 70 times more acute than our sense of taste.

Logarithmic scale

- Fechner's Law [3]
  - Subjective sensation is proportional to the logarithm of stimulus intensity
- Impulse frequency from sensors is proportional to the logarithm of stimulus intensity [4]

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The logarithm principle of subjective sensation was first discovered by Gustav Fechner.

The fact that the sensory nerves generate impulses based on the logarithm of the stimulus intensity is important because

1/ When you add or subtract logarithms of values it is equivalent to multiplying or dividing the source values and

2/ Neurons fire when the sum of the exciting stimuli minus the inhibiting stimuli exceed their threshold value.

Animal Action Devices

- Biological - External
  - Muscles (600 muscles, 200 joints)
    - Movement
    - Speech
- Dependent muscles are:
  - Next to each other (adjacent)

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Most animals use muscles to perform their actions.

Muscles are used:

1/ in limbs for moving

2/ in the diaphragm for breathing

3/ in the tongue, larynx and mouth muscles for speaking.

But they are not all interdependent, for example, the tongue is independent of limbs.

There are also internal devices that can be controlled (or not) such as the heart, stomach secretions, and hormonal responses.

Action Devices → Sensors

- Action devices have corresponding sensors
  - Distinguish between actions initiated by
    - Oneself
    - Externally
- Spatial layout in the brain
  - Sensory and motor homunculi [5]

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Every action device has sensors to detect what it is doing.

Sensor relationships and action device relationships are spatially represented topographically in the brain and spinal cord.

There is a cortical homunculus, a map of somatosensory (touch) areas and corresponding motor areas in the brain.

At the primary motor cortex, motor representation is arranged in an orderly manner, inverted.

The toes are represented at the top of the cortex, while the mouth is represented at the bottom of the cortex, closer to the lateral sulcus.

And the layout of the sensors on the input side correspond to the same layout of the muscles on the output side.

Robotic Action Devices

- Motors / actuators (movement)
- Speakers (sound)
- Lights / projectors (light)
- Heaters (heat)
- Etc.

Robots have a larger selection of action device types.

However they are all directly or indirectly activated or controlled by electricity.

Action Devices → Responses

- In psychology a response is:
  - The action produced
- Definition for Adaptron includes
  - The signal sent to an action device
  - The signal produced by a neuron
    - An output
    - It may stimulate another neuron

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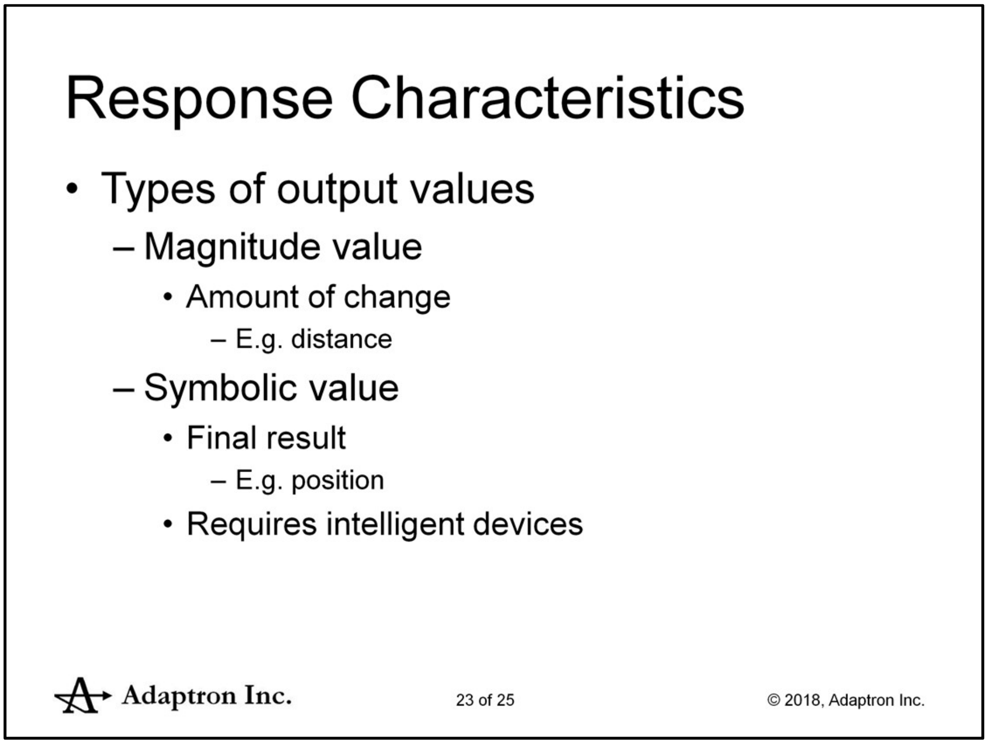
For Adaptron purposes a response is the output signal to an action device giving it information about what to do.

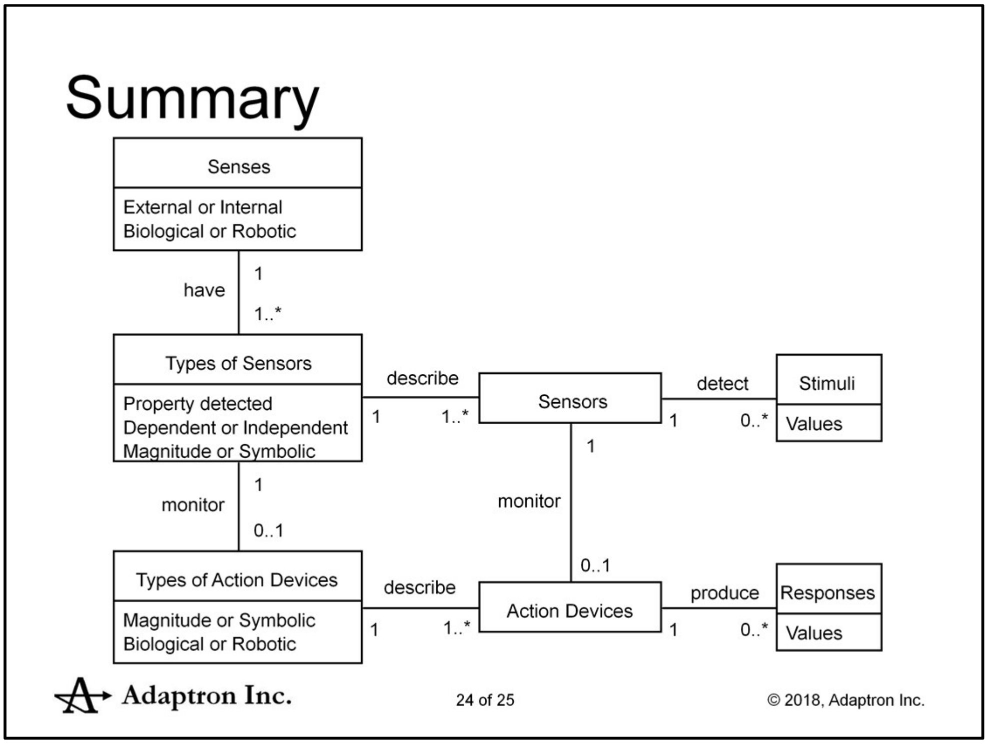
But it is also the signal output by a neuron that becomes a stimulus for another neuron.



The response can be an instruction to make a certain change (magnitude value) or perform a specific task (symbolic instruction).

To perform a specific (symbolic) task the action device must know how to do it.

To perform a change the device needs to be less intelligent.



This is a UML class diagram.

It describes the subjects covered in this presentation, their properties and the relationships between them.

References

[1] Gallistel, C. R. (1990). The Organization of Learning [book]. Cambridge, Massachusetts: MIT Press

[2] Weber-Fechner law - https://en.wikipedia.org/wiki/Weber-Fechner_law

[3] Fechner, G.T. (1966). Elements of psychophysics (Vol. 1) E.G. Boring & D.H. Howes (Eds.); H.E. Adler, (Trans.). New York: Holt, Reinhart & Winston. (Originally published in 1860)

[4] Granit, Ragnar (1955). Receptors and Sensory Perception [book]. New Haven and London: Yale University Press

[5] Cortical homunculus - https://en.wikipedia.org/wiki/Cortical_homunculus

Gallistel is an exceptional author. His writing is clear and easy to understand.