Interface Devices

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

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This presentation describes the detailed design of interface devices as required by Adaptron.
Interface devices are the senses and action devices that are part of a robots body that allow it to sense and have an effect of the environment.
Sensors and actuators are parts of Adaptron that allow it to use these interface devices.

I explain these subjects from a functional and mechanistic perspective.

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 presentation on Binons.

Contents

This presentation covers such subjects as:

Grounding and embodying behaviour on the interface devices,

External and internal senses,

Sensors and their properties,

Sensor resolution based on the Just Noticeable Difference as described in psychophysics by Weber and Fechner,

The sense of time,

And action devices and actuators.

I will be describing both animal and robot interface devices.

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
      - Senses and action devices
      - Supported in an infrastructure
        - » The body

Animals and robots need to be grounded on their environment in which they are situated.

The senses and action devices serve this purpose. They allow it to be in touch with reality and can make changes to it by performing actions.

We say that a system of components, such as Adaptron is embodied, when it uses senses and action devices that make up the infrastructure of an agent's body.

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

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.

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 (yaw, roll and pitch)
- Clock (time)
- Etc.

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

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

Internal senses can be used to detect 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.

Senses are Independent

- Measure independent sources of energy
- Multimodal perception
  - Done by the brain
- Timing dependency
  - Temporal coincidence
  - Recognizing patterns in time

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.

Many Sensor Types per Sense

- Each sensor type detects a different property
  - Sensor types are independent
- Examples
  - Touch
    - Heat (Thermoreceptors)
    - Pain (Nociceptors)
    - Four mechanical types of receptors
  - Sight
    - Colour (cone cells)
    - Brightness (rod cells)

Each sense has one or more types of sensor and each sensor type detects and measures a different property.

So sensor types are independent just like the senses.

For example in the retina of the eye, the two sensor types are cones and rods. Cones measure colours and rods measure brightness.

There are six types of sensors in the skin. Heat is detected by thermoreceptors and pain in detected by nociceptors.

Four are types of mechanical sensors for pressure, light touch, regular touch and skin stretch.

Dependency and Coincidence

- Coincidence required to recognize relationships between things
- Spatial dependency
  - Positions → Shapes
- Temporal coincidence
  - Simultaneous
    - Spatial patterns
  - Sequential
    - Temporal patterns

Relationships between things are recognized as a result of spatial dependency and temporal coincidence.

For example, 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.

But temporal coincidence is required to recognize anything.

When adjacent sensor readings change simultaneously a spatial pattern such as a shape can be recognized.

When sensors change sequentially then temporal patterns such as speech and motion can be recognized.

Note that not all sensors of the same type are necessarily next to each other in an array and therefore may be quite independent.

This is often true for proprioceptive sensors because the action devices they monitor are independent.

For example, the tension in the muscles in your limbs while walking is quite independent of the tension in your tongue while talking.

A robot example is the rotational positions of wheels on a car are independent of each other.

Example: Hearing

- A one dimensional array of sensors
  - Hair cells
  - Measure the volume of sound
  - For a given pitch / frequency
  - Over time
- Two ears provide direction information

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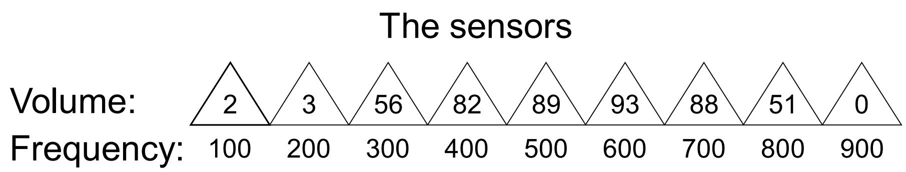
Let's investigate a simpler sense. Even though hearing is complex it is much simpler than vision and touch. It only measures one property and that is loudness or volume in physics. Each volume measured is for a different frequency or pitch in music. The hair cells are the sensors and each one is tuned to a specific frequency based on its place in the cochlea.

Example: Hearing

- A simplified model of a single ear
  - Volume measurements are the stimuli
  - Measure sound at an instance in time



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This is a model of the volume measurements at different frequencies from a single ear at an instant in time.

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

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 the sound from playing a chord on a piano but instead of the sound of vibrating strings it is composed of pure sine wave frequencies. The sound of a real chord from a piano string has its own timbre and is quite complex.

Sensor Measurement Values

- Non-symbolic values (numeric)
  - Interval scale (e.g. position, time)
    - 21, 22, 23, 24, etc.
  - Ratio scale (e.g. intensities)
    - Such as lightness, distance, loudness, weight, etc.
      - 0, 2.0, 3.9, 47.2, etc.
- Symbolic values (discrete)
  - Nominal (e.g. tree, pencil, blue, door, etc.)
    - ♌ ❒ ♐ ♒ ❍ ⚐ G Ω ¥ β
  - Ordinal scale
    - A, B, C, D, E, etc.

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The values measured via the sensors can be non-symbolic or symbol. Non-symbolic ones are numeric. They can be divided into interval and ratio scale.

Interval scale values are numeric with an equal distance between the values, such as temperatures (in Celsius or Fahrenheit but not Kelvin). Positions or times and dates are also interval scale properties. The value of zero is totally arbitrary in an interval scale.

Ratio scale values are real numbers and have a zero corresponding to nothing being measured. Examples are intensity values such as for lightness, pressure or loudness.

When you subtract one interval scale value from another you produce a ratio scale value. For example the difference between two positions is a distance.

When you divide one ratio scale by another you produce a ratio. For example the ratio of two widths may indicate that one object is half as wide as another. You can do this with temperatures in degrees Kelvin but not Celsius or Fahrenheit.

Symbolic values are most useful in recognition because they are discrete and do not vary like numeric ones. No arithmetic can be performed on symbolic values.

They can be divided into nominal and ordinal scale.

Nominal scale values allow names (or integers) to be assigned to things. Words are typical examples of nominal scale symbolic values.

But they can also be individual symbols or characters.

An example of an ordinal scale would be the alphabet. The letters are in a particular order and can be sorted.

Sensors that produce numeric values are simple devices while those that produce symbolic values are far more sophisticated because they have to be intelligent enough to recognize something.

Sensing Relational Properties

- Using the sign of differences
- Positive, zero or negative
  - Above, on/in, under (position → distance)
  - Before, during, after (time → delay)
- Using ratio values relative to one
  - Bigger, same, smaller (size)
  - Louder, same, quieter (sound intensity)
  - Longer, same, shorter (duration)
  - More, equal, less (repeat count)

After calculating the difference between two interval scale values the result is a ratio scale value that maybe positive, zero or negative.

This sign is a symbolic feature that indicates whether something is above on or under for distances and before, during or after for delays

After deriving the ratios of ratio scale values and comparing them with one, relational features can be determined. For example, bigger, same and smaller in size,

louder, same or quieter in sound intensity, longer, same or shorter in duration and the more, equal or less number of things.

Just Noticeable Difference (JND)

- Resolution of numeric values
  - Determined by sensor precision
- Weber's Law [2]
- 100 grams versus 101 grams
  - NOT noticeable
- 100 grams versus 110 grams
  - IS noticeable

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The resolution of the non-symbolic/numeric sensory values is based on the precision to which the sensors can measure them.

The idea of a Just Noticeable Differences (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. And is different for different types of sensors.

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.

Jones (1989), in a force matching experiment about the elbow, found a JND ranging between 5% and 9% [3]. 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 [7]. 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 are tabulated below :

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)

Logarithmic scale

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

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In 1860, Gustav Fechner, a psychophysicist, discovered that subjective sensation is proportional to the logarithm of the stimulus intensity.

This is important because using logarithms in calculations allows division to be done by using subtraction.

The Log(A/B) = Log(A) – Log(B). This can be used in the calculation of ratios. Ratios are important in the representation of relationships.

This is also biologically plausible because neurons fire when the sum of the exciting stimuli minus the inhibiting stimuli exceed their threshold value.

For those interested in spiking models of neurons, it has also been shown that impulse frequency is proportional to the logarithm of stimulus intensity.

Sense of Time[1]

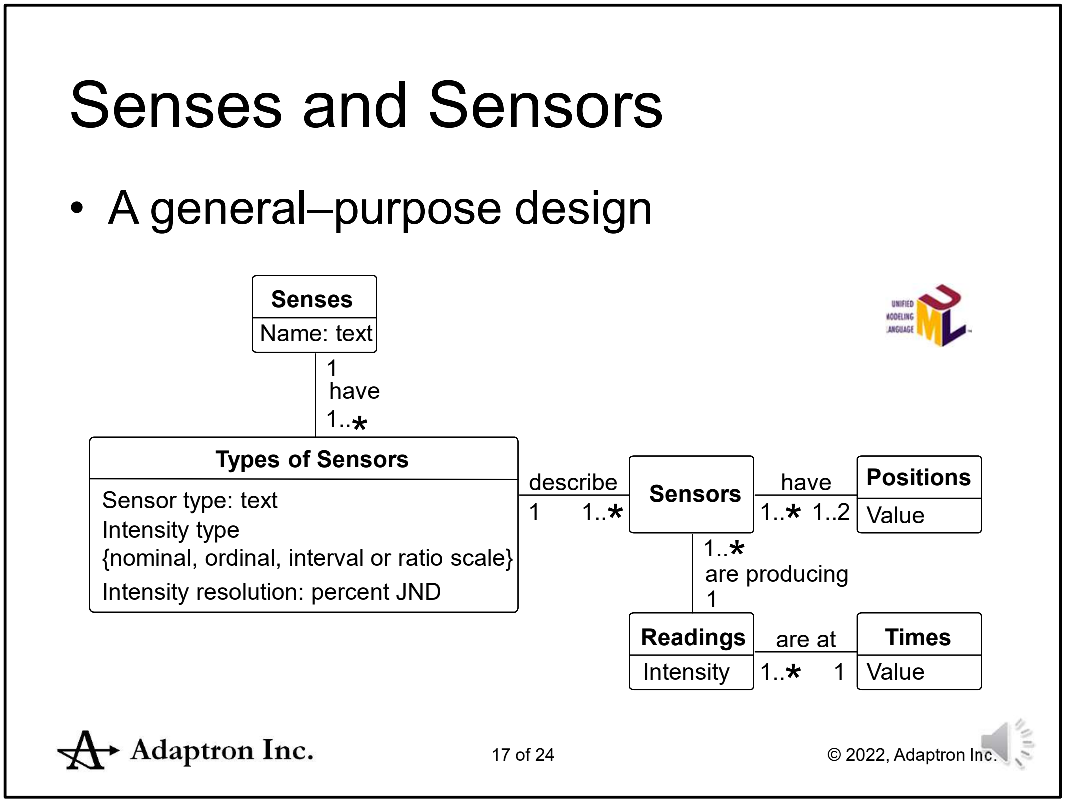
- Events are adjacent in time
  - Sequential and Dependent
- Time is an interval scale value
- Duration is a ratio scale value
  - The time between two event boundaries
  - Temporal recognition
    - Speech
    - Motion
    - Morse code

Somewhere in our nervous system we have a sense of time. Events occur in time and are sequentially dependent.

Time is an interval scale value because the position of time zero is arbitrary.

However the time between two events is duration and that is a ratio scale value. A duration of zero is possible and makes sense.

And patterns of duration provide for the recognition of temporal sequences as found in speech, motion and the dits and dahs in Morse code.



Software programmed for perceiving things needs to operate on a large variety of senses and sensors.

A generic design for senses and sensors is captured in this Unified Modeling Language (UML) class diagram.

A sense can have one or more arrays of sensors, each of a different type but each sensor type belongs to only one sense.

There are many sensors of each type.

Information needs to be read from sensors to recognize not only what something is but also to determine where and when it occurred.

Therefore, sensors are producing readings of intensity values at an array position and at a point in time. They may have one or two positions depending on whether they form a one or two-dimensional array. This design assumes that sensors are equally spaced in their arrays, which is not the case for animals. Animal senses are far more sophisticated than this simplified design.

Sensory Memory

- Core properties
  - Position, Intensity, Time
  - Held in sensory memory
  - Accumulates references to percepts
- Sensors are scanned
  - Percepts repeat and are counted
    - Spatial and temporal
- Two frames
  - Spatial and temporal

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The resulting core set of amodal (i.e., not sense specific) properties are position (where), intensity (how much), and time (when).

Sensory memory holds these core values per sensor and accumulates references to the percepts found from scanning the sensors for their readings.

Spatial and temporal repeat counts (how many) are important core properties needed in perception and they are determined by the sensory memory.

There are two frames in sensory memory. The first one is spatial and keeps sensory properties from the current time interval.

The second frame keeps track of previous sensory properties to determine when sensory values change and the duration between changes.

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

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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.

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Robots have a larger selection of action device types. They are all directly or indirectly activated or controlled by electricity.

Response Characteristics

- Types of output values
  - Magnitude value
    - Amount of change
      - E.g. distance
  - Symbolic value
    - Final result
      - E.g. position
    - Requires intelligent devices

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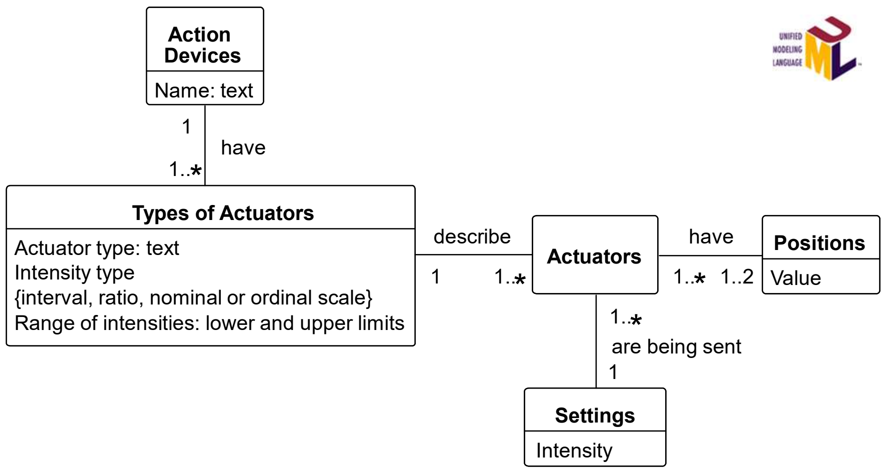
The response can be an instruction to make a certain change (magnitude value) or perform a specific task (symbolic instruction).

To perform a specific task the action device must know how to do it. To perform a change the device needs to be less intelligent.

Action Devices and Actuators

- A general–purpose design



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This a UML class diagram for action devices and actuators.

It describes their properties and relationships between them.

References

[1] Gallistel, C. R. (1990). *The Organization of Learning*. 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] Ragnar, G. (1955). *Receptors and Sensory Perception*. New Haven and London: Yale University Press

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

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