Applied Neuroscience

Columbia Science Honors Program
Fall 2016

Emotions and Language

Emotion and Language

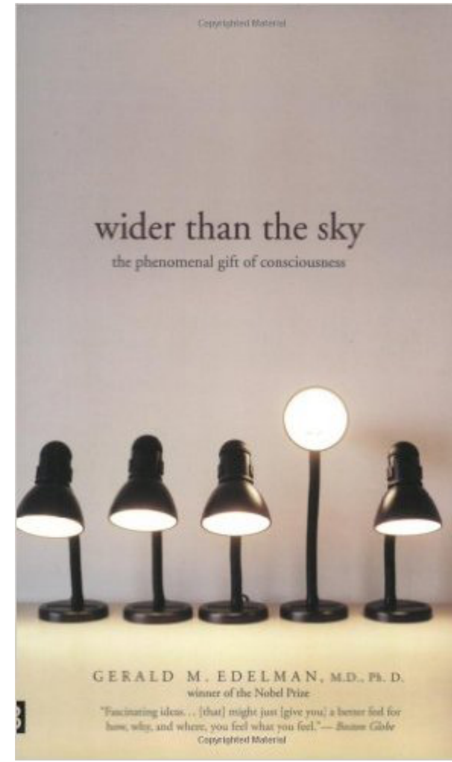
Objective: Cognition and Computation

Agenda:

1. Emotions
   - *Science of Inside Out*
   - *Neurobiology*
2. Language
   - *Neurobiology*
3. Emotion Recognition Software
   - *Pepper*
   - *Android Erica*

Inside Out

Inside Out: Metaphor of Neuroscience



Central Command

Control panel is operated by different emotions.

Do we have a central command?

We do not have a “seat of consciousness.”

Rather, consciousness is highly distributed. We do have the limbic system that regulates emotions.

Headquarters of Inside Out: Hippocampus

Each time Riley experiences an event, a memory sphere of that event rolls into Headquarters. These memories can move into long-term storage.

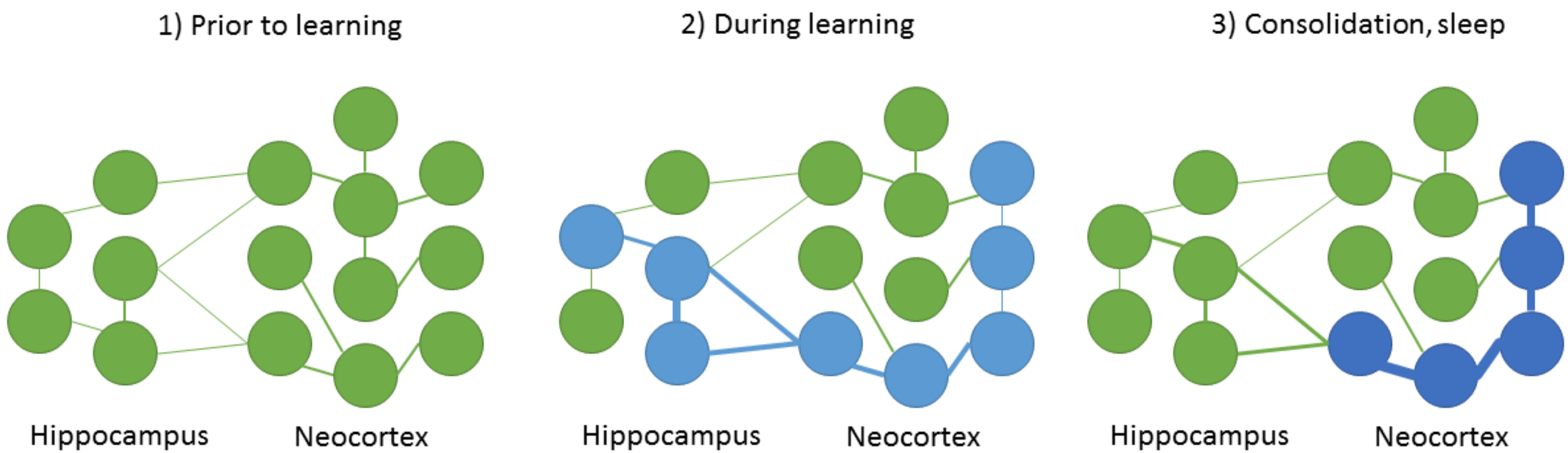
Hippocampus:
component of limbic system that is vital for the formation of episodic memories

Episodic Memories:
memory of autobiographical events (memories that consist of a what, when, and where)

Without a hippocampus, people can no longer form new episodic memories. Which patient is an example of this?

Patient HM: He had his entire hippocampus removed due to seizures.

Consolidation of Memories



Once the hippocampus has formed an episodic memory, where do these memories then go?

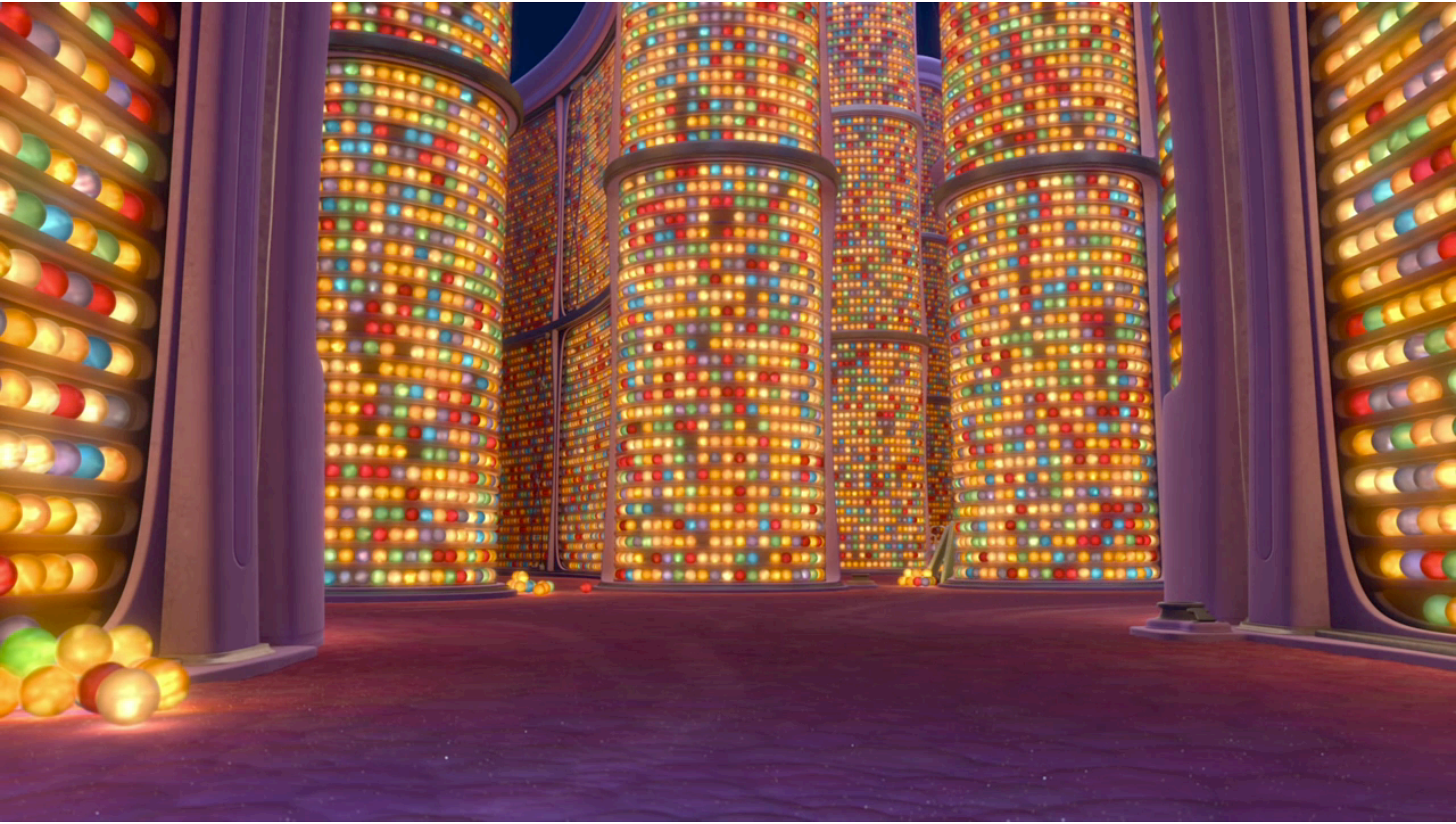
Cerebral Cortex

Consolidation:

Process of maintaining a memory for long-term storage

Sleep is believed to play an important role in consolidation of memories from the hippocampus to the cortex.

Inside Out: Long-Term Memory



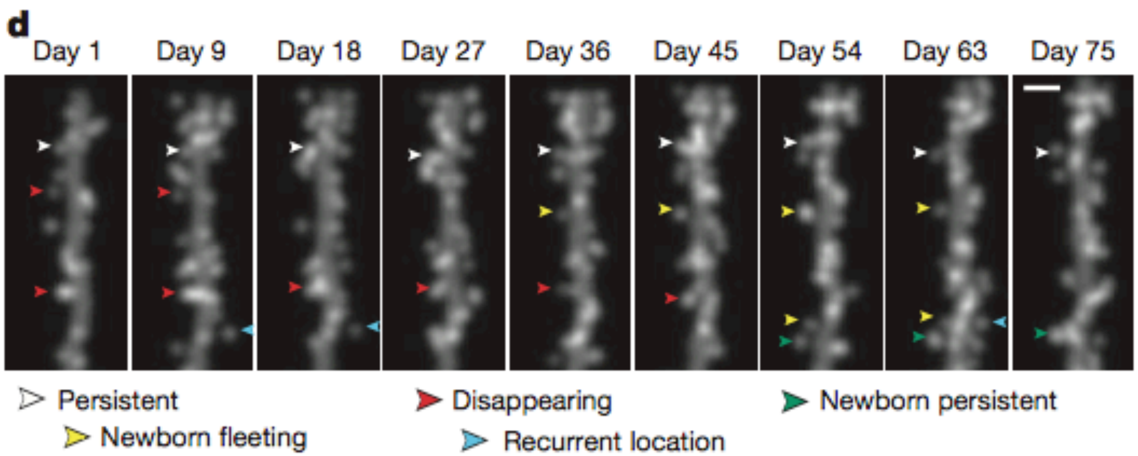
Neurobiology of Long-Term Memory

Is there evidence for the process of memories leaving the hippocampus to the cortex in vivo?

Yes: the laboratory of Mark Schnitzer at Stanford found that hippocampal synapses persist for time intervals that match the known duration of hippocampal dependent-memory.

Background:

- Mammalian hippocampus transiently retains information for about 3-4 weeks in adult mice and longer in humans
- Neural synapses are the elemental sites of information storage

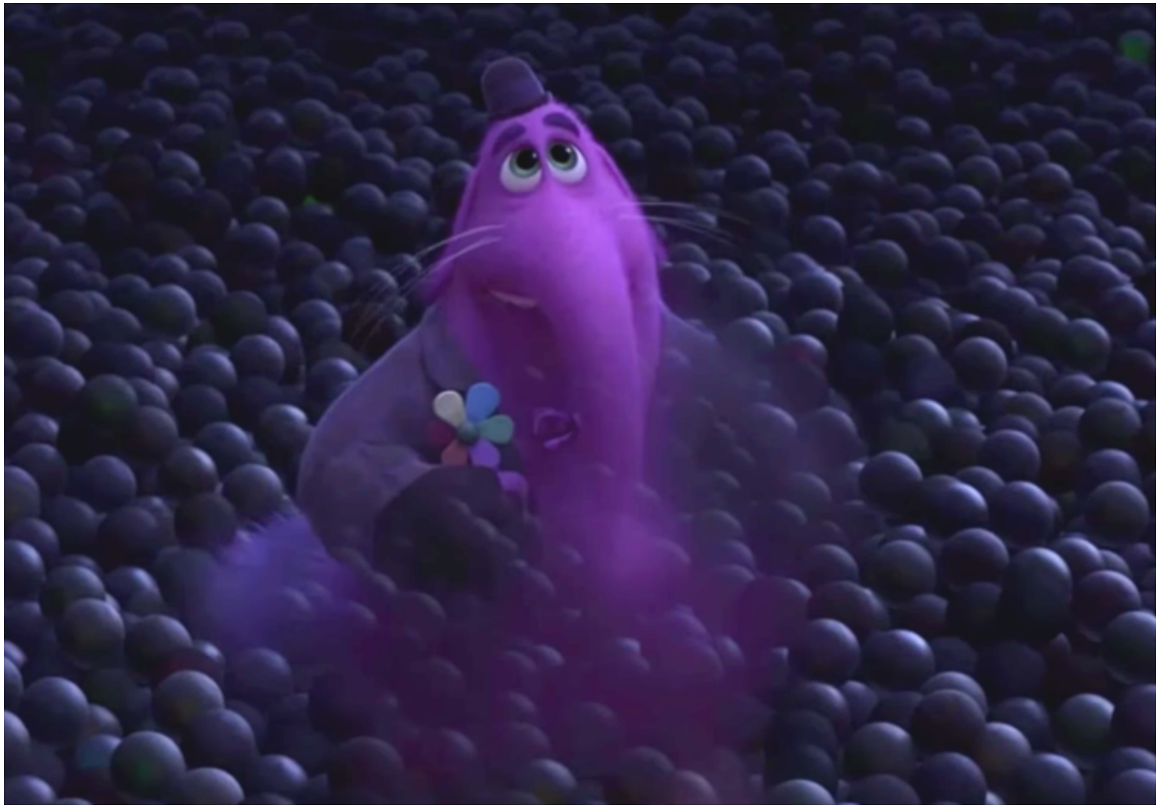


Time-lapse two-photon microendoscopy of hippocampal area of live mice was done to monitor dendritic spines of pyramidal neurons

Results:

Dendritic spine dynamics in the hippocampus was distinct from that of the cortex. In this study, spines had a mean lifetime of 1-2 weeks. This implies 100% turnover about 2-3 times.

Inside Out: Forgotten Memories



Inside Out depicts the degradation of a long-term memory as its loss of color and glow. Some memories turn to a puff of dust. In neuroscience, there are many theories as to how we forgot memories.

Cue-Dependent Forgetting: failure to recall memories without a cue

Rather than the memory being gone, this theory implies that it was simply hard to access.

Trace Decay Theory: memory trace decays and is lost permanently

Where are memories physically stores?

Dendritic Spines: spines can degrade and their connections can be lost. This is important in selectivity of memories.

Physical Traces of Memory

Inside Out depicts memories as luminous spheres. In neuroscience, an episodic memory is represented by a neuronal ensemble.

Engram: theoretical representation of how memories are stored (physical or chemical changes in response to external stimuli)

Inside Out: Emotions

Emotions: internal states expressed by behaviors

- Triggered by specific stimuli (extrinsic or intrinsic to environment)
- Functional and adaptive role

Are emotions a cause or consequence of their associated behaviors?

Charles Darwin argues for consequence.

William James argues for cause.

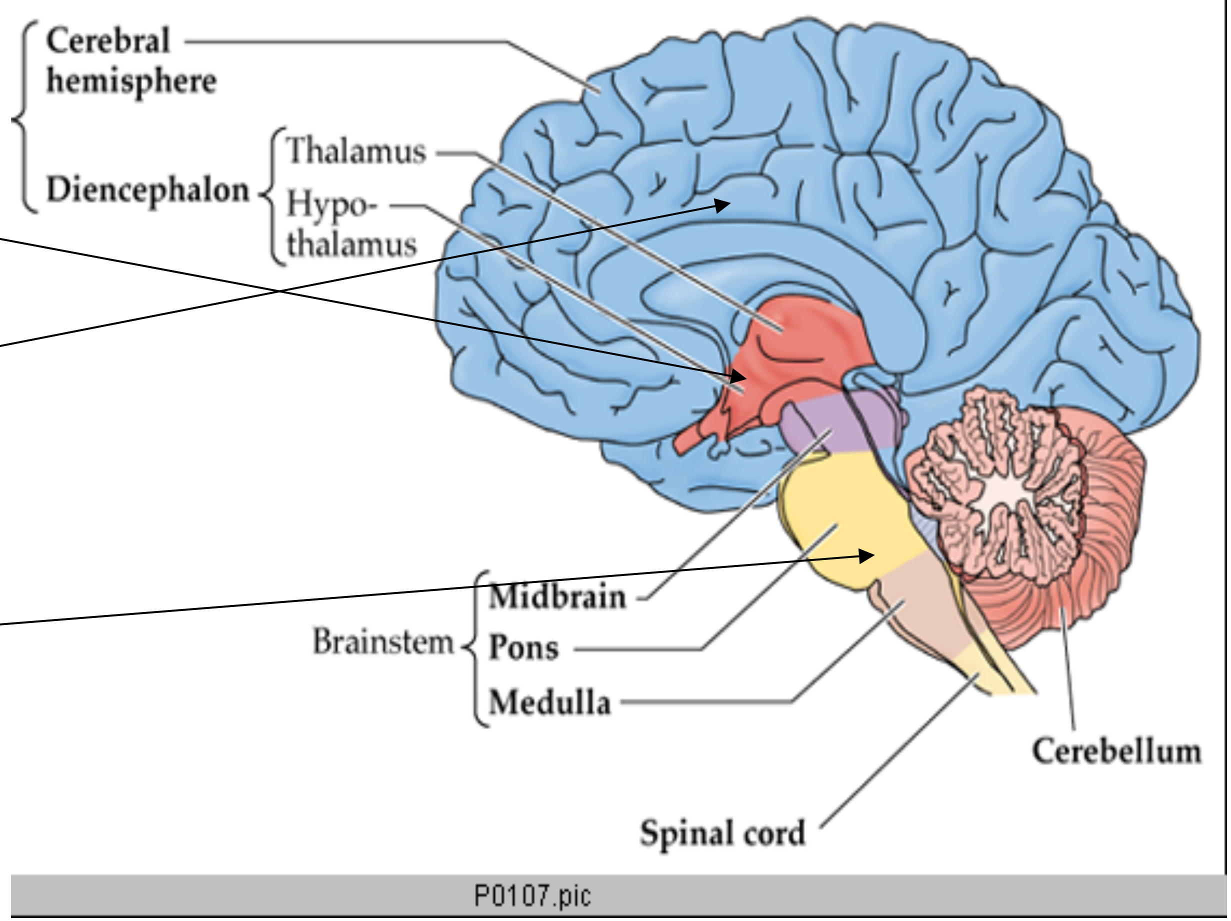
“I feel *afraid* because I run from the bear; I do not run because I feel afraid.”

Brain Structures that Mediate Emotion

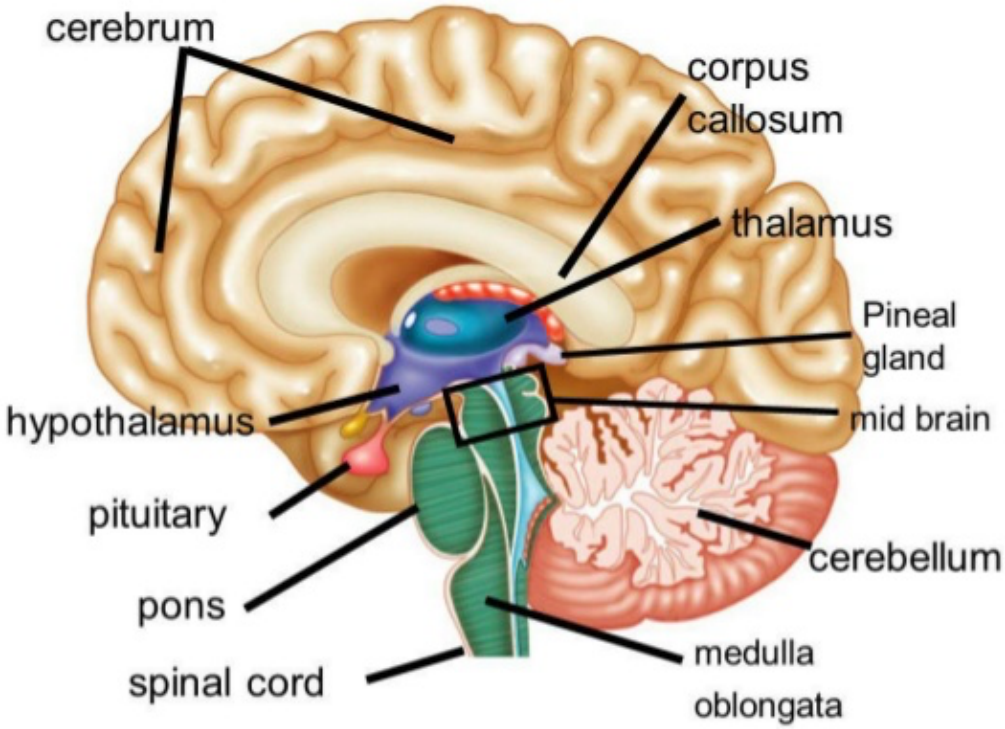
Amygdala: a major structure leading to patterns of physiological change which pause when emotion occurs

We may have an emotional response prior to awareness

1. Hypothalamus
2. Limbic System
   - ❖ limbic cortex
   - ❖ amygdala
3. Brainstem



Hypothalamus



What is it?
A deep brain structure made up of a number of nuclei

Where is it?
Under the thalamus at the base of the fore brain and behind the optic chiasm

What does it do?
Integration of emotional response
Endocrine response

- neuro-secretory
- oxytocin and vasopressin

Hypothalamus

How do we know that the hypothalamus integrates emotions and behaviors?

- Ablation studies
- Stimulation studies
- Primary emotions: fear and anger

Ablation Studies

Cats

Remove cerebral hemispheres: rage

Remove cerebral hemispheres and hypothalamus: no rage

Behavioral response is reversed with small lesions in the hypothalamus.

Stimulation Studies

Lateral hypothalamic stimulation: rage

Other areas in hypothalamus: defense, fear

Ablation Study in Cats

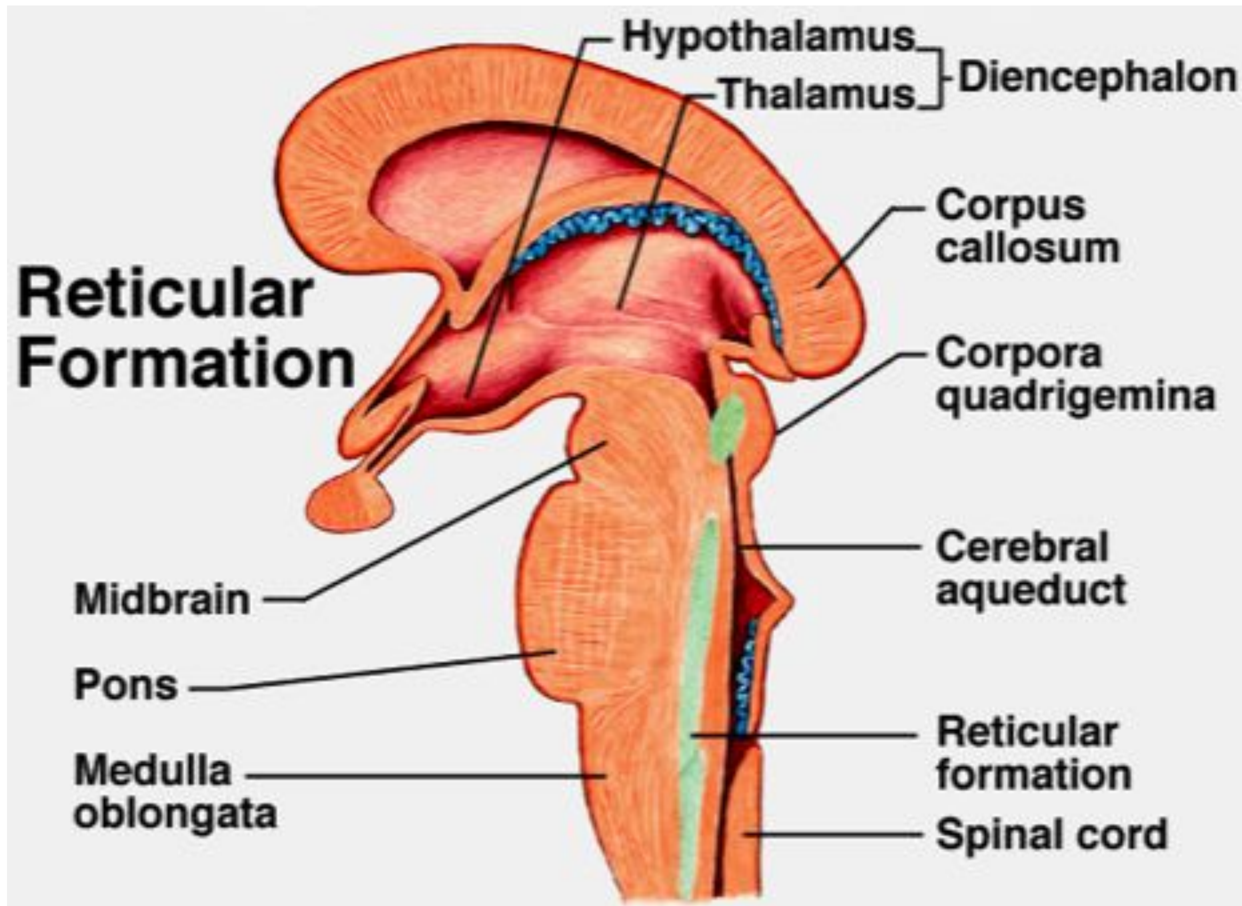
Hypothalamus

Integrates and routes information on emotions

- **Input:** Unprocessed information from Cerebral Cortex
- **Output:** Processed information to Reticular Formation

Reticular Formation:

- Brain stem
- 100+ cell groups
- Controls sleep-wake rhythm, arousal, and attention



Reticular Formation

- Receives hypothalamic and cortical output
  - Separate descending projects that run parallel to motor systems
- Output to somatic and autonomic effector systems
  - Cardiac response
  - Respiratory response
  - Excretory response
  - Coordinates brain-body response

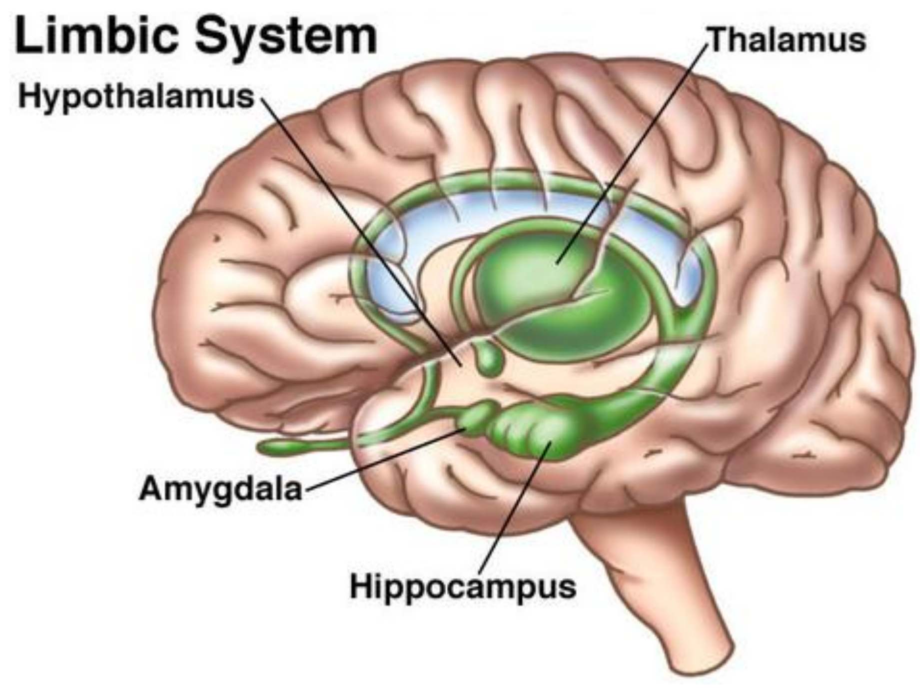
Limbic System

Primary emotions: reactions to external events
Secondary emotions: how you feel about the feeling itself

- Uses higher cortical processes

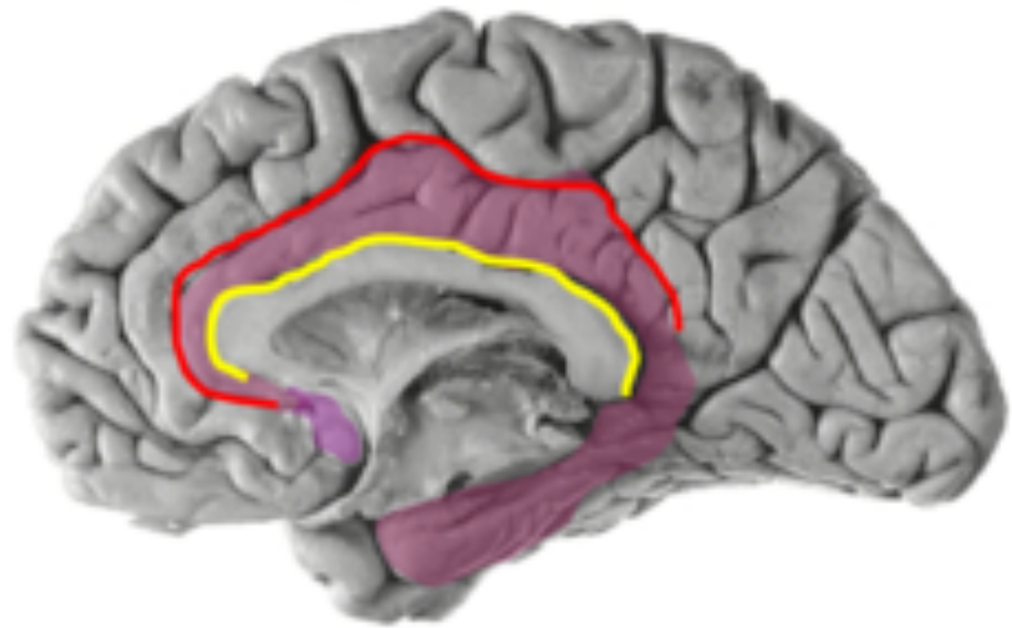
Limbic System

- Link between higher cortical activity and “lower” systems that control emotional behavior such as hypothalamus
- Limbic lobe
- Consists of deep-lying structures
  - Amygdala
  - Hippocampus
  - Mamillary bodies



Limbic Lobe

What is it?
- Cingulate gyrus
- Para-hippocampal gyrus

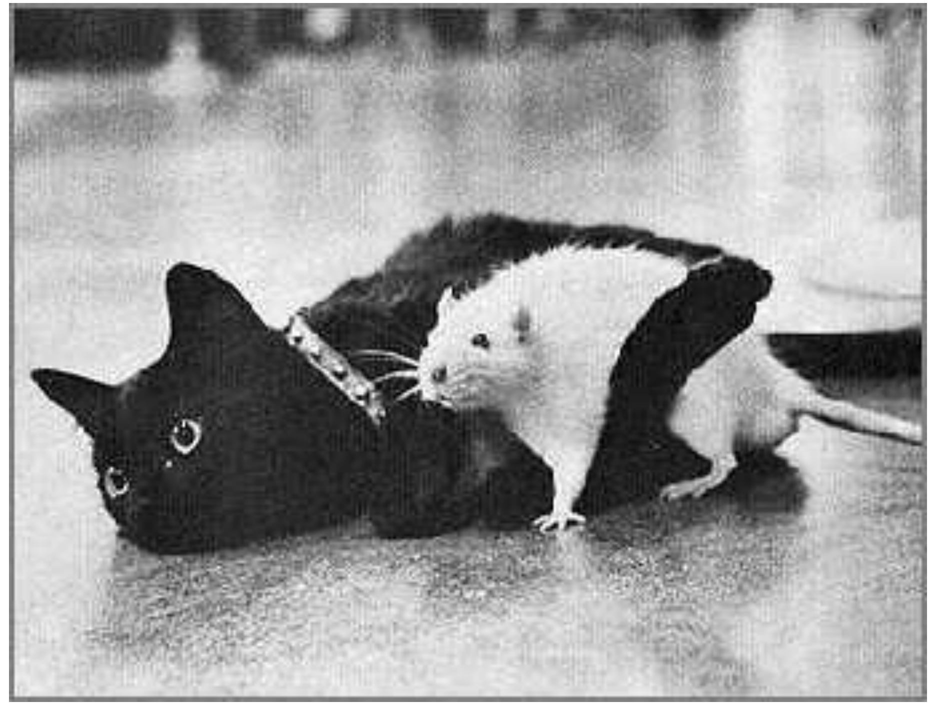


Where is it?
- Encircles the upper brain stem
- Surrounds corpus callosum

What does it do?
Integrates cortical information

How do we know this?
Kluver-Bucy Syndrome

Kluver-Bucy Syndrome



Removal of temporal lobe in animals

Pre-operative:
aggressive, raging

Post-operative:
Docile, orally fixated, increased sexual and compulsive behaviors

Symptoms in Humans:

- Amnesia
- Docility (diminished fear response)
- Hyper-sexuality

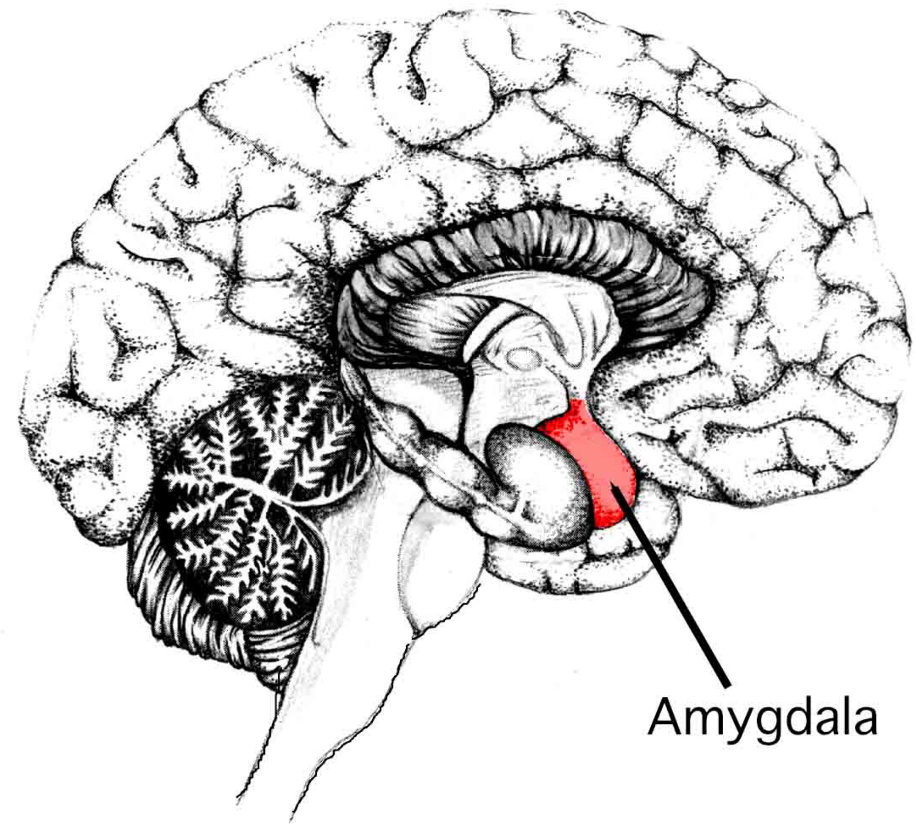
Amygdala

What is it?
Nuclear mass
Almond-shaped

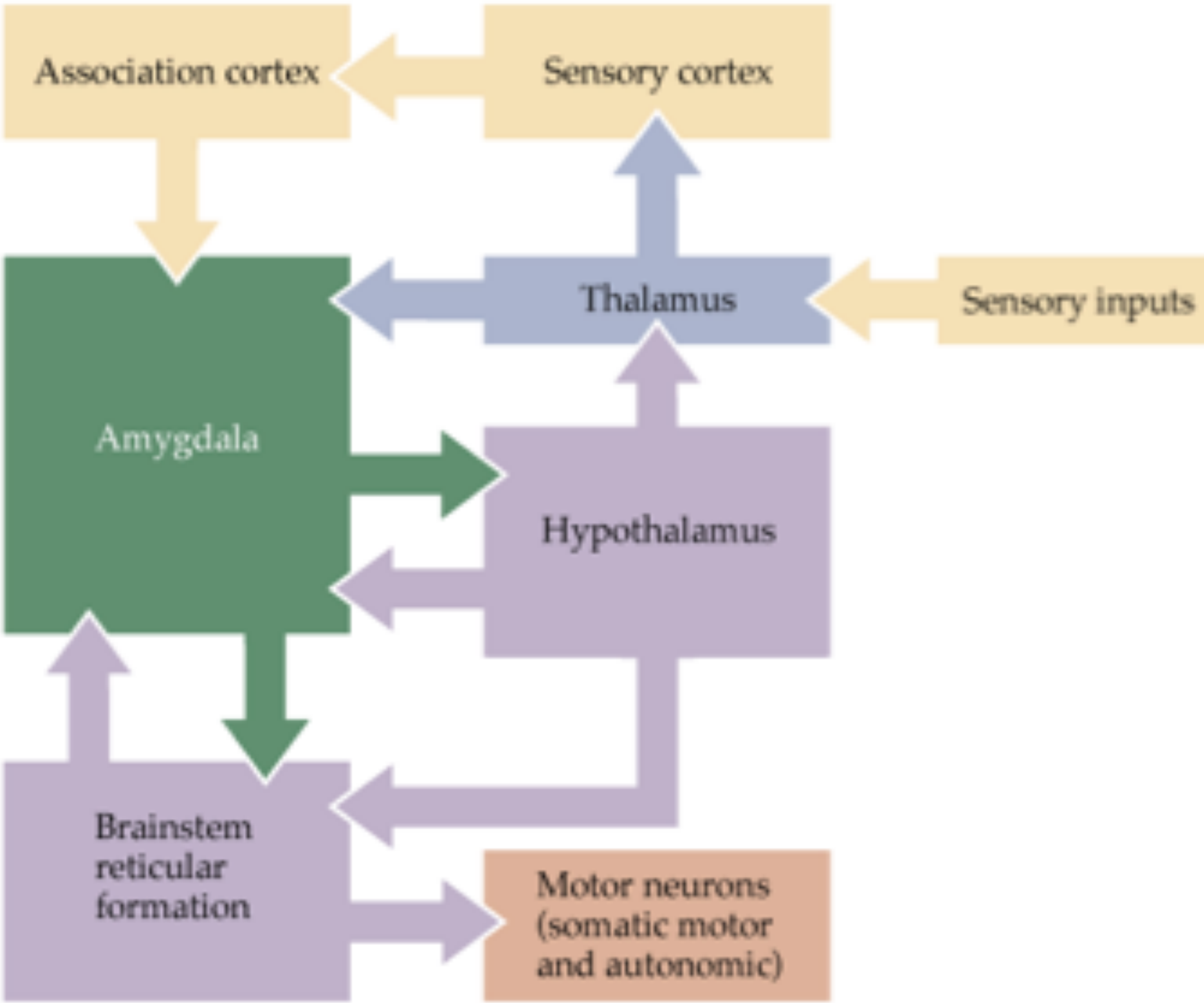
Where is it?
Buried in the matter of the temporal lobe, in front of the hippocampus

Connects to:

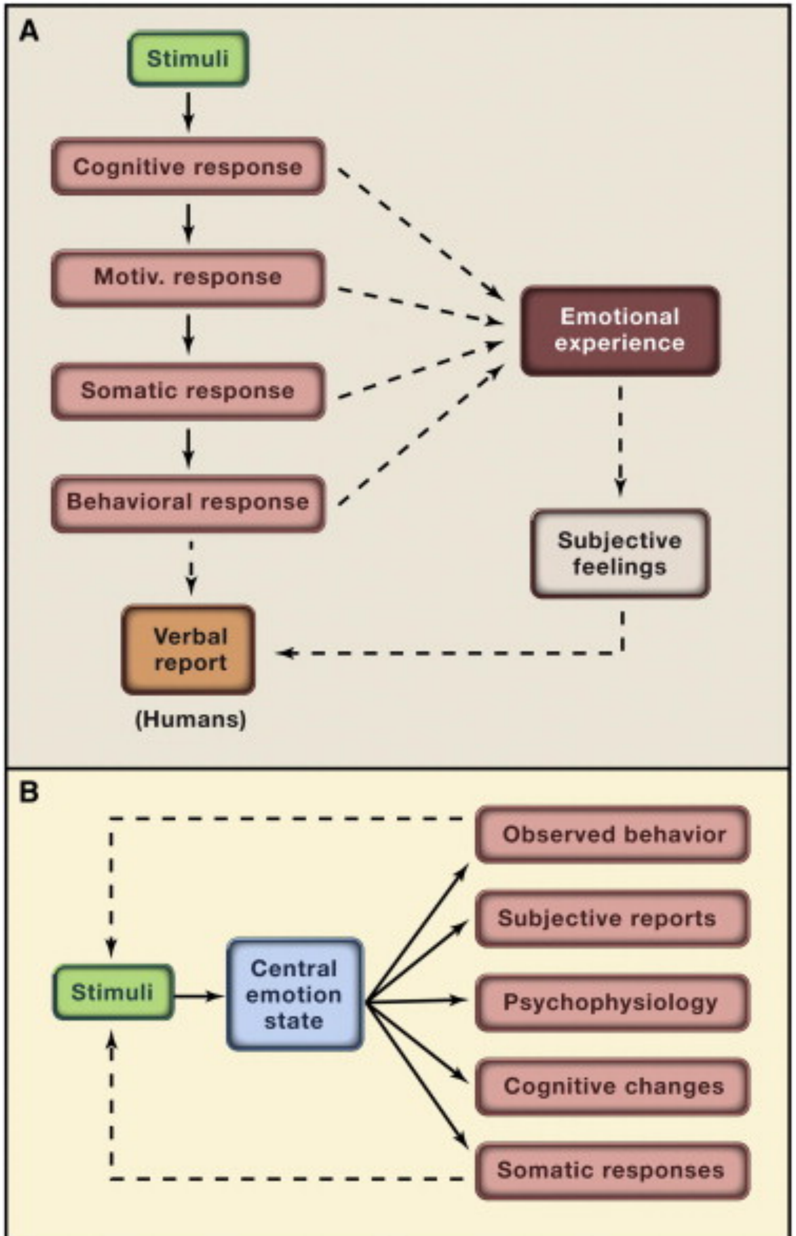
- Olfactory bulb and cortex
- Brainstem and hypothalamus
- Cortical sensory association areas



Anatomy of Emotions



Emotions: Central, Causative States



A. Traditional View

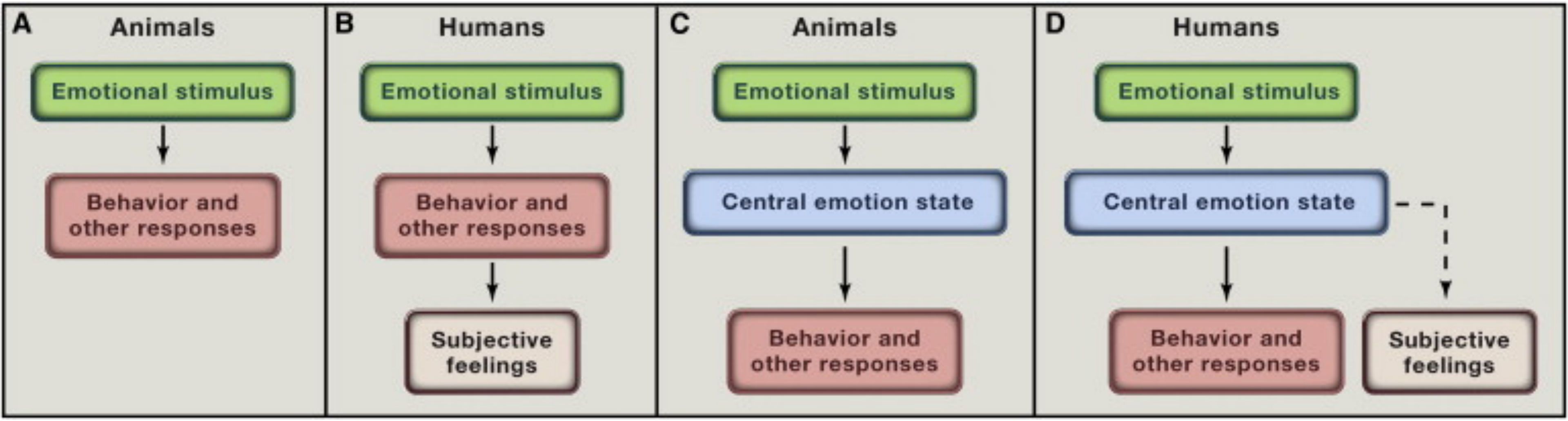
Emotions are distinguished by multiple components that need to be coordinated and often synchronized.

B. Updated View

Emotions result in multiple components that need to be coordinated and often synchronized.

A central emotion state results in multiple parallel responses.

The Relationship between Emotions and Feelings



A, B. Traditional View

Emotional stimuli evoke behaviors and other responses. In humans, the subjective feelings of emotions is assumed to arise from our conscious awareness of behavioral and somatic responses to stimuli.

Is there a seat of consciousness in animals?

C, D. Updated View

Responses to emotional stimuli are mediated by central emotion states. In humans, those central states produce feelings in parallel with behavior and other responses.

Test Your Understanding: Emotions

During emotional states, epinephrine and norepinephrine are released because of activation of which of the following?

A. Cortex
B. Thalamus
C. Amygdala
D. Sympathetic Nervous System

What is the part of the limbic system involved in regulating emotion?

A. Cortex
B. Hypothalamus
C. Amygdala
D. Adrenal Gland

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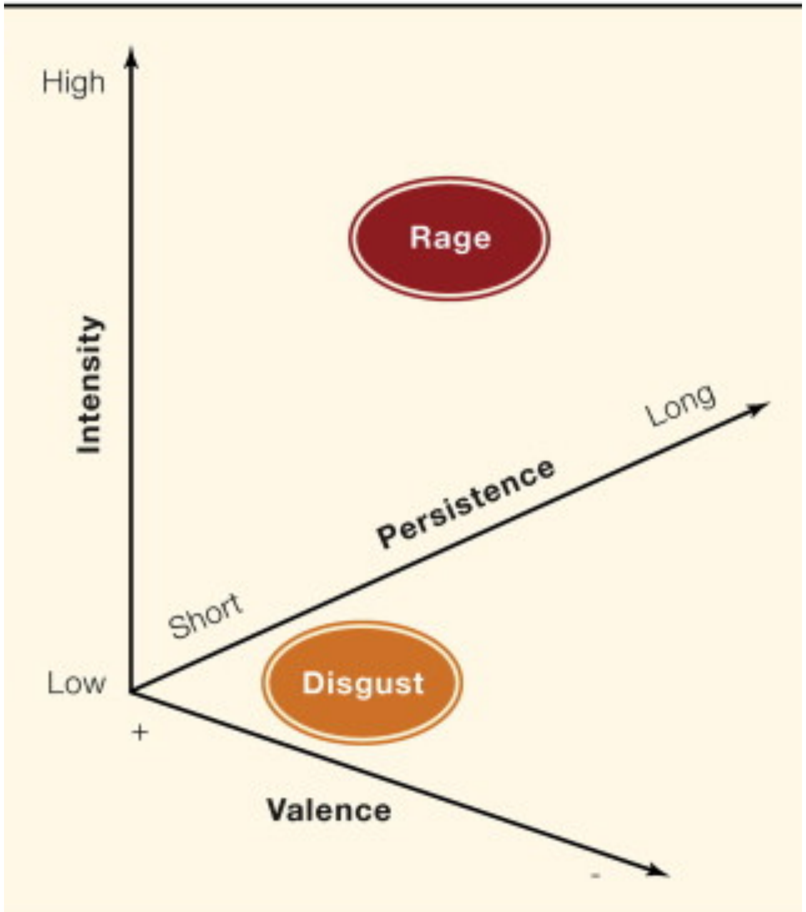
Central Emotion States



Features of Central Emotion States:

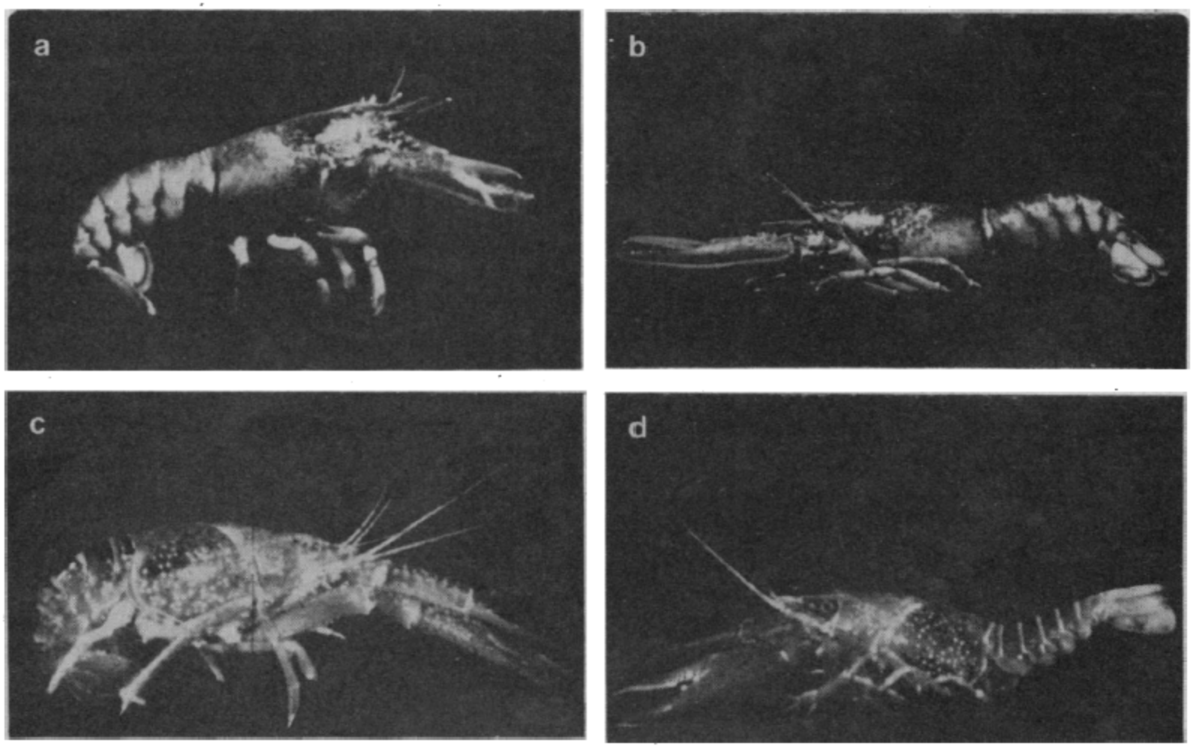
Scalability: gradations of intensity

Example: Defensive Behavior

- freezing (avoid detection) to flight (avoids capture)
- In octopi, switch from *crypsis* (camouflage) to ink jetting and propulsion

Central Emotion States

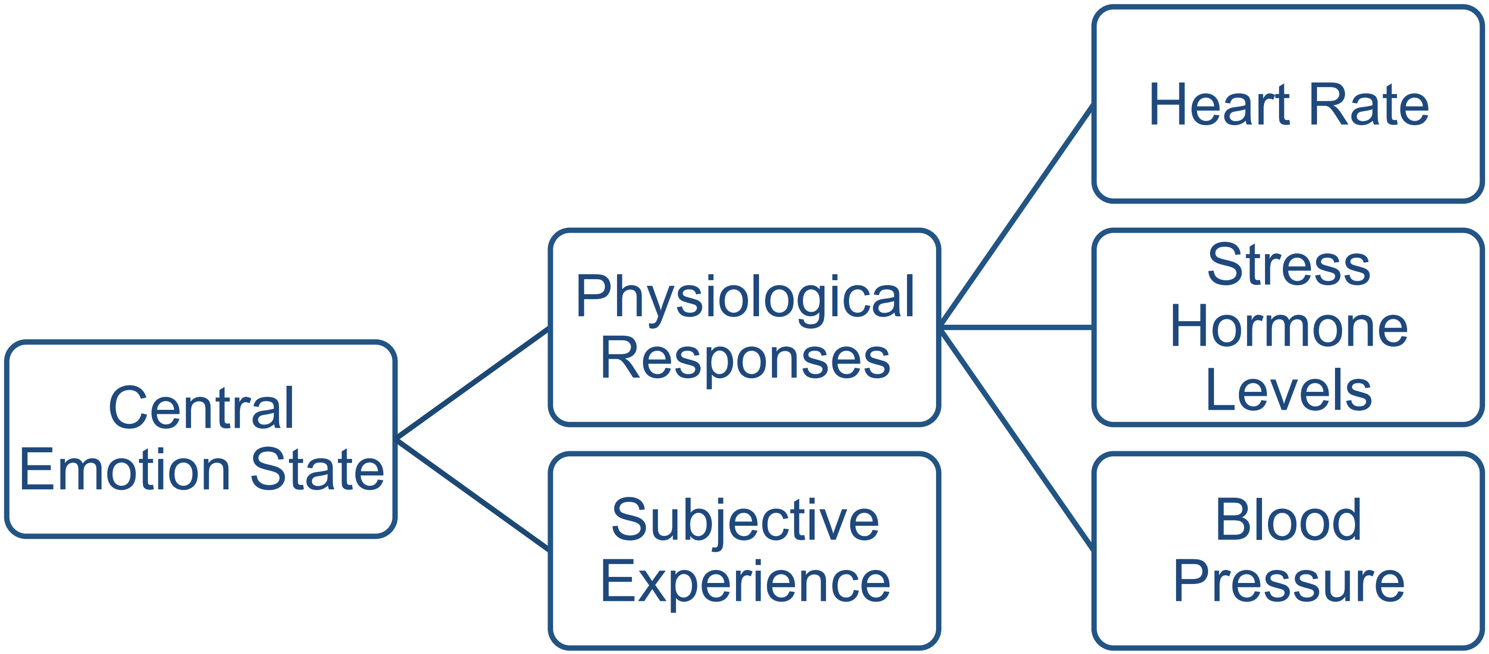
Features of Central Emotion States:
Valence: emotions come in opposites
Example: withdrawal v. approach to an object
measured by locomotor activity
Valence can be the result of chemicals, namely *serotonin* and *octopamine*.



Octopamine injection produces sustained extension of the limbs and abdomen; serotonin injection produces sustained flexion.
A, B. *Lobster*
C, D. *Crayfish*
(Livingstone, 1980)

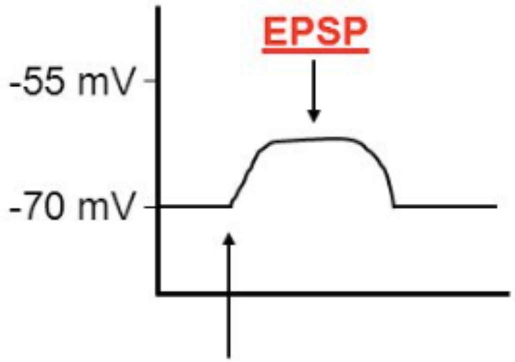
Central Emotion States

Features of Central Emotion States:
Persistence: distinguishes emotional behaviors from simple stimulus reflexes
Emotional behaviors outlast the stimuli that elicit them.



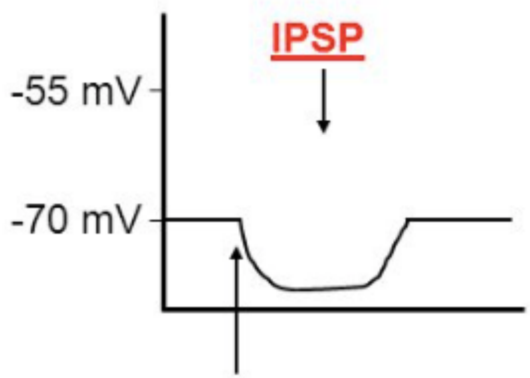
Interoception: term that represents the brain’s detection of the body’s internal state

Neural Integration



Nt binds and opens channels allowing Na^+ or Ca^{2+} influx

Depolarization = EPSP $\xrightarrow{?}$ AP



Nt binds and opens channels allowing Cl^- or K^+ efflux

Hyperpolarization = IPSP $\neq$ AP

Neural Integration:

Process of summing (integrating) signals

There are two types of signals that represent post-synaptic responses:

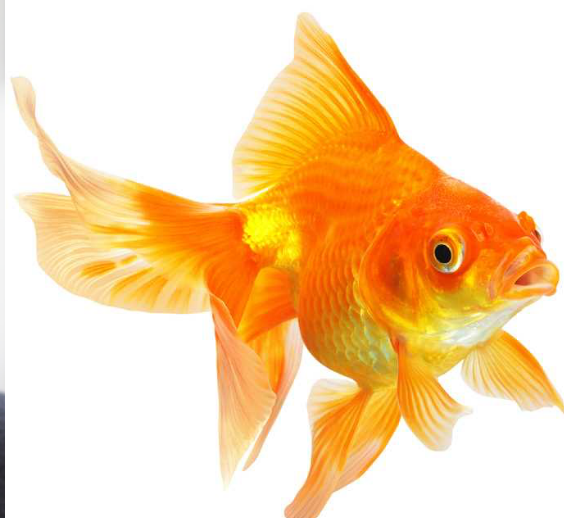
1. **Excitatory Post-Synaptic Potential:**
   - bring neuron closer to firing
   - graded depolarization
2. **Inhibitory Post-Synaptic Potential:**
   - move neuron farther away from its firing level
   - graded hyperpolarization

Integration occurs on two levels:

1. **Single-Cell** (Neuronal) Level
2. **Circuit** (Neuronal Ensemble) Level

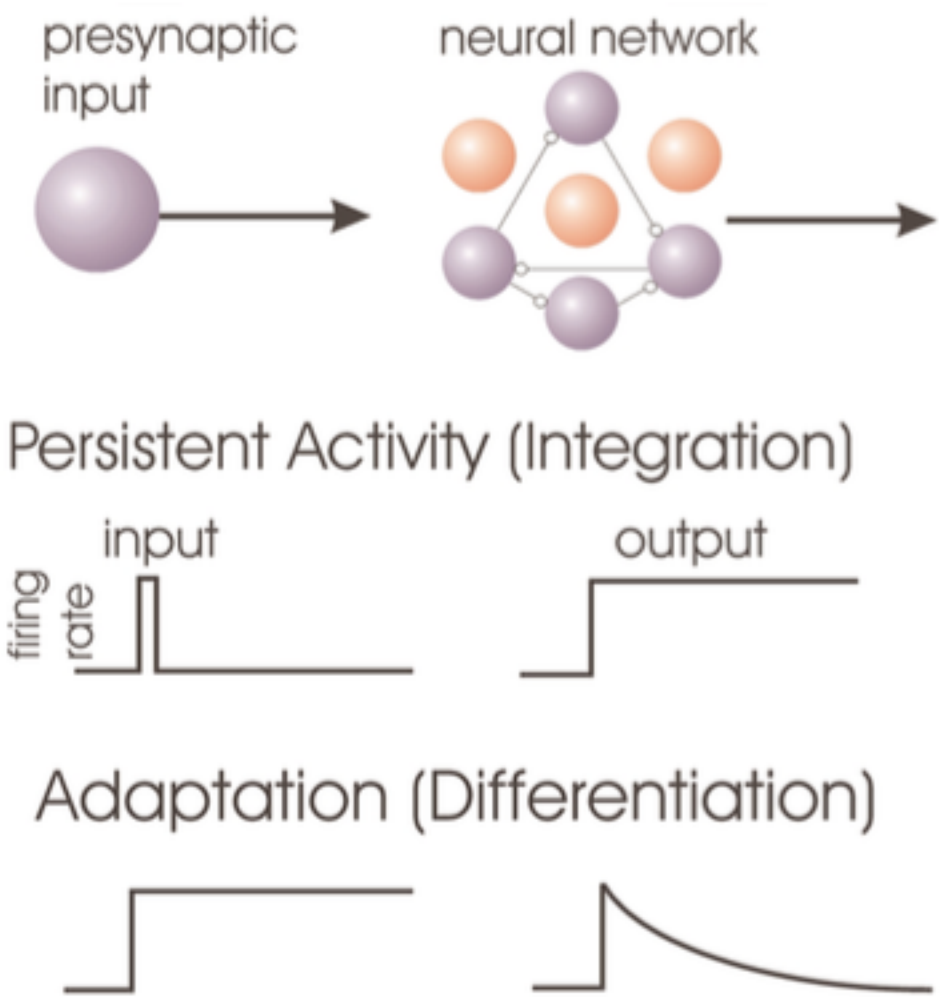
Brain Calculus: Neural Integration and Persistent Activity

How does the brain keep track of external and internal behaviors?
Hypothesis: Sustained synaptic excitation generated by reverbatory interactions among neuronal ensembles (Hebbian Learning)



Experiment by Laboratory of David Tank:
Why test the visual system?
Our eyes scan the world by rapid movements known as **saccades.** Each saccade is separated by a **fixation point.** A fixation point requires continuous contraction of eye muscles, ***which is an example of persistent activity that uses working memory.***
Why goldfish?
Goldfish continuously scan the visual world through a series of horizontal saccades.

Brain Calculus: Neural Integration and Persistent Activity



Each fixation point is maintained by persistent activity of neurons in the goldfish brainstem known as **Area I.**

How do we know so?

If Area I is inhibited, the goldfish loses the ability to fixate and instead gazes after each movement.

How is persistent activity generated?

Re-entrant excitation and transient activity through adaptation. Adaptation is the activation of hyperpolarizing currents or synaptic depression.

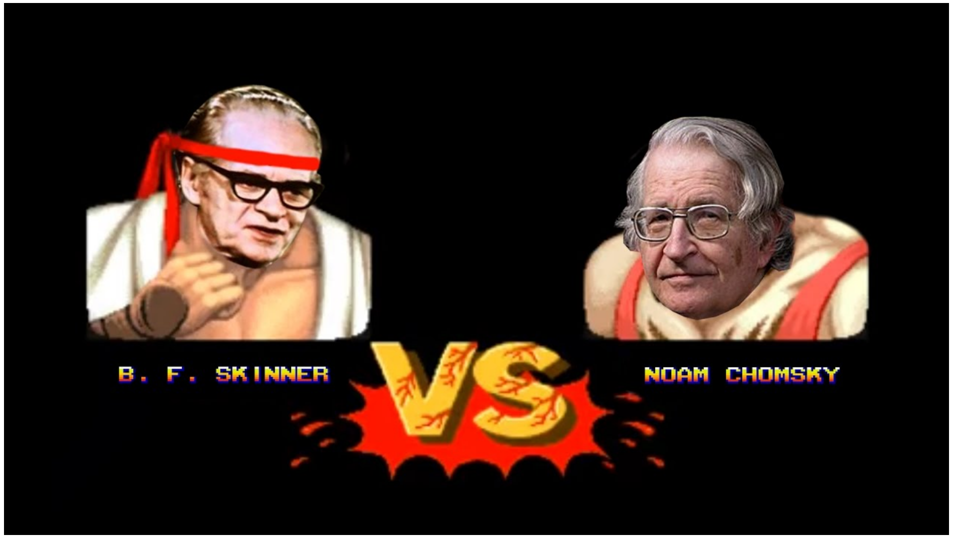
What is Language?

1. Communication through words or symbols for words
2. Words are an association between sound and meaning
3. By 6 years, children understand about 13000 words
4. By 18 years, high schoolers understand about 60000 words.

Is language learned or innate?

Question of development being learned or innate was brought up by neuroscientists Skinner and Chomsky in the 1950s.

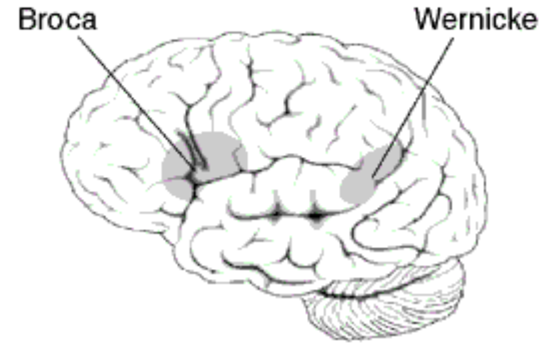
Both men had different views and theories on the same study of how humans manage to obtain grammar.



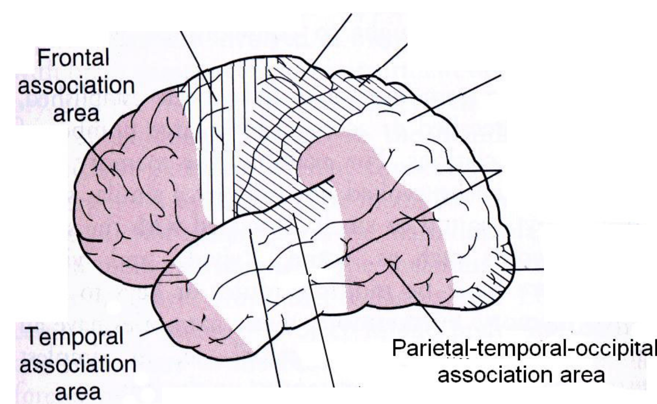
Chomsky's Theory	Skinner's Theory
Innate biological ability that all humans possess – every child has a "language acquisition device"	Learning process involving the shaping of grammar into a correct form by the re-enforcement of other stimulus.
Innate learning mechanisms enables a child to figure out how language works	Approaches child as a blank slate that is filled up with knowledge gained through experience.

Modern framework of language

Implementation system: Broca's and Wernicke's areas analyze incoming speech in terms of phonemes and other grammar



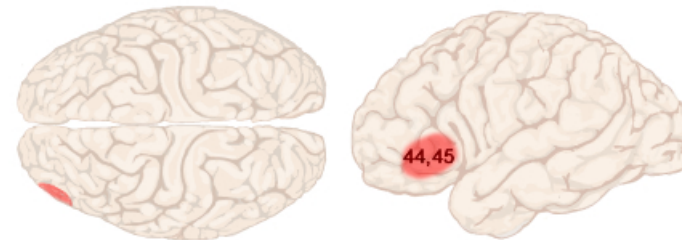
Mediational system: Areas of the temporal, parietal and frontal association cortices that surround the implementation system make up the mediational system. This system allows for communication between the implementation and conceptual systems.



Conceptual system: Areas distributed throughout the association cortices are important in learning, memory and conceptual knowledge.

Different types of Aphasia

Broca Aphasia (non-fluent aphasia)**:**
Speech output is severely reduced and limited mainly to short utterances of <4 words. They can understand speech well and are able to read, but are limited in writing.



Wernicke Aphasia (fluent aphasia)**:**
The ability to grasp the meaning of spoken words is impaired, while the ease of producing connected speech is not affected. Speech is not normal. Reading and writing is severely impaired.

Conduction Aphasia:
Speech production and comprehension are less affected than Broca or Wernicke aphasias. Sentences are not repeated accurately and they have trouble naming pictures and objects.

Global Aphasia:
All disabilities of Broca, Wernicke and Conduction Aphasias.

What does this actually look like?

Type of Aphasia	Auditory comprehension Stimulus: **“What kind of trouble are you having?”**	Capacity for repetition Stimulus: **“Please repeat this sentence: the stray animal was timid.”**
Broca	*“Well, um… see… I um… not sure.”*	*“Timid.”*
Wernicke	*“I’m having some trouble.”*	*“Um… eh…”*
Conduction	*“I can’t seem to, my sentences, the words having trouble saying.”*	*“The dog was… what was that last word?”* **(“Let me repeat it: The stray animal was timid.”)** *“The dog was… um…”*
Global	*(no words, only gestures)*	*(no response)*

Artificial Emotion in Robots

Why is emotion important?
People tend to treat computers as they treat **other people.**

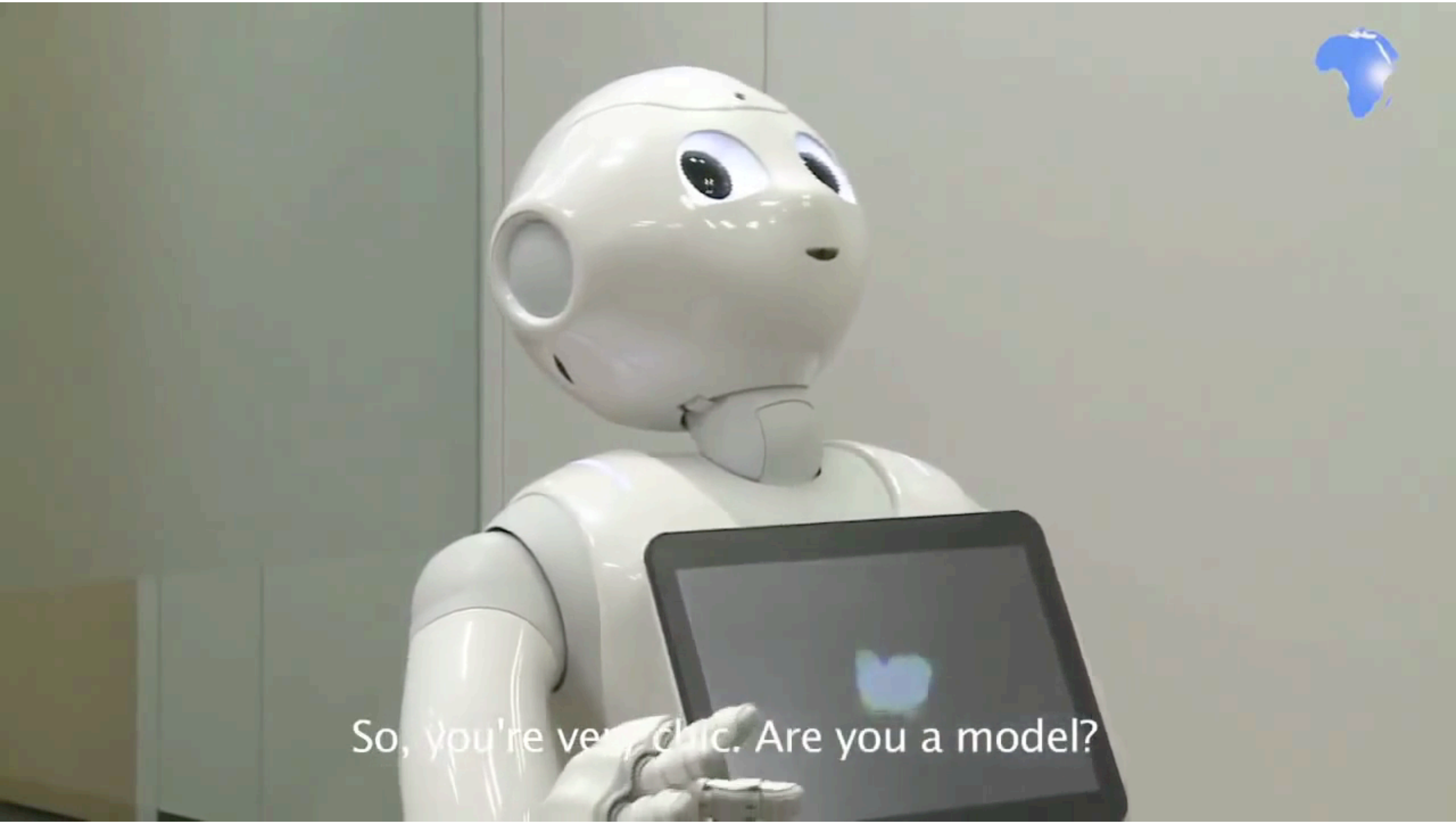
Artificial emotion used in social robots

- Emotion aids human-robot interactions
- Provides feedback to user
- Acts as a control mechanism

How do robots display emotion?

- Design-of-frameworks vary in size

Pepper: First Robot with Artificial Emotion



About Pepper

Hearing and Speaking: 4 directional microphones allow Pepper to detect where sound is coming from

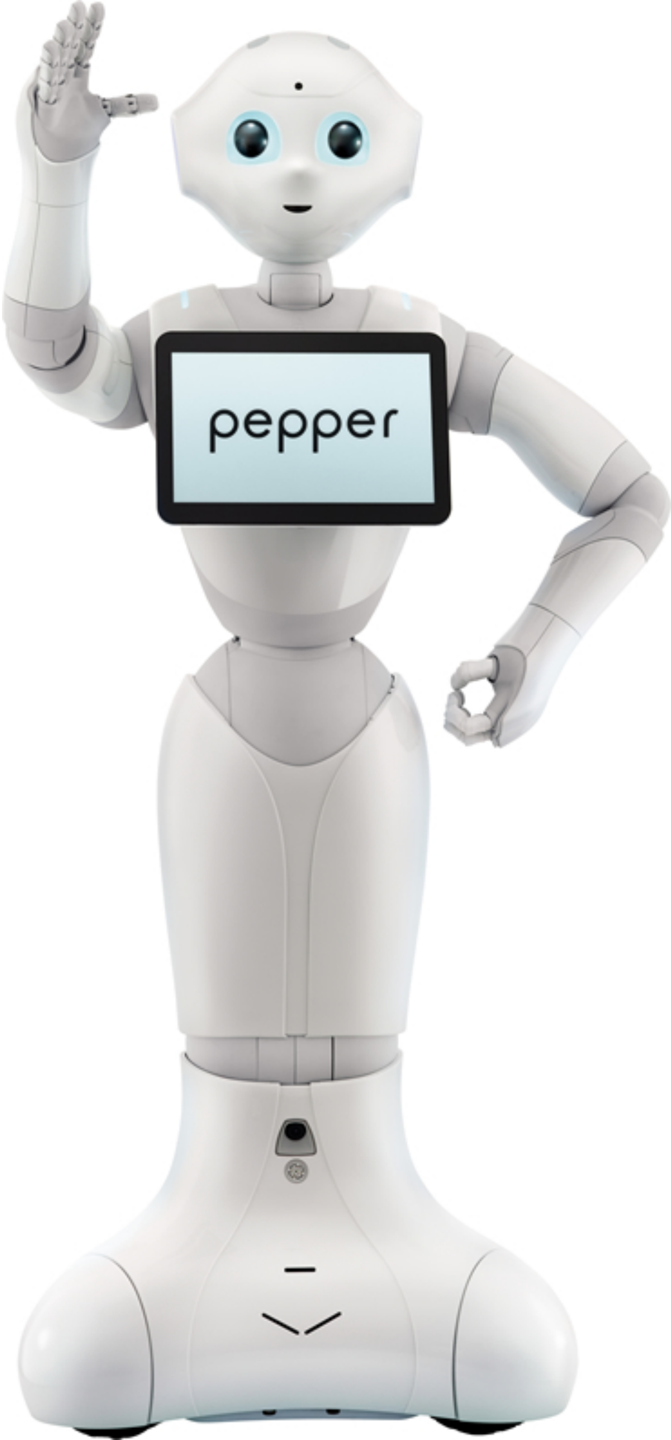
Vision: 2 HD cameras and 1 3D camera in Pepper's head, which allows him to identify movements, objects, and faces with enough detail to recognize emotions

Connection: On-built Wi-Fi

Tablet: Pepper can express his emotions with this

Emotion Engine: By perceiving and analyzing your emotions, Pepper is able to adapt his attitude to suit your own as closely as possible

Movement: 3 multi-directional wheels and 20 engines, and an anti-collision system



Emotion Recognition Software

People express their emotions through multiple modalities:

- Human speech
- Facial expressions
- Body pose

Emotional feature and signs

Robots like Pepper recognize the user's emotional state through:

Emotional analysis and recognition

- Audio
- Visual
- Physiological signal

Emotional psychological background

Human computer interaction (HCI)

Emotional Speech Analysis

- Speech is a major channel for communicating emotion
- Speech signal conveys

  Textual, lexical, emotional and gestural information
- The set of features in the speech signal
- Classification Algorithm

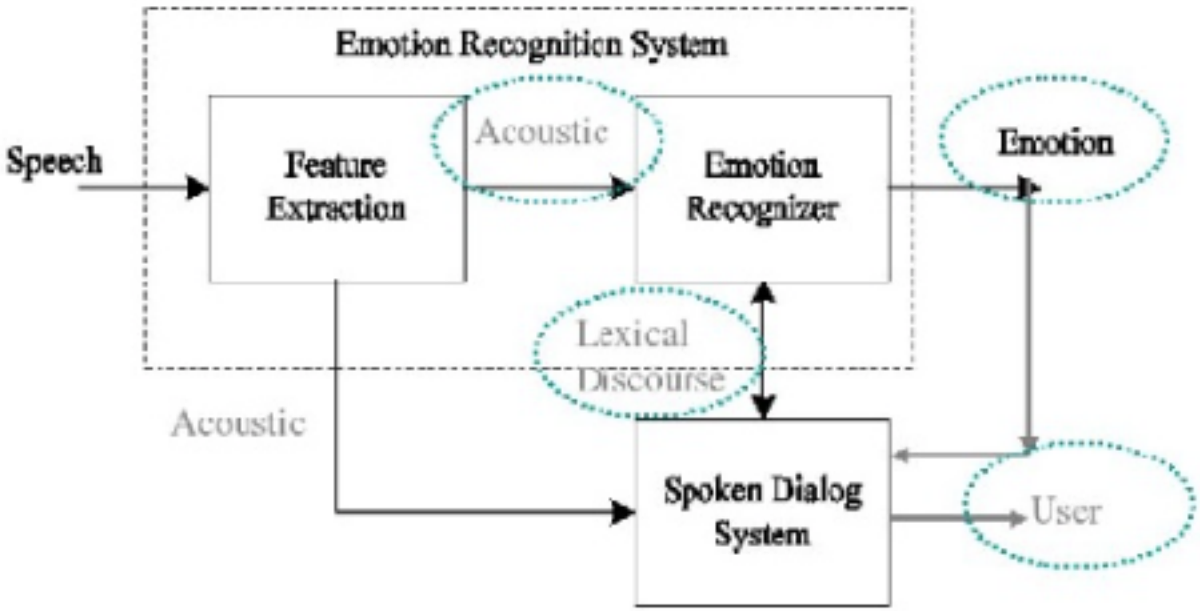
  1. The Static Approach

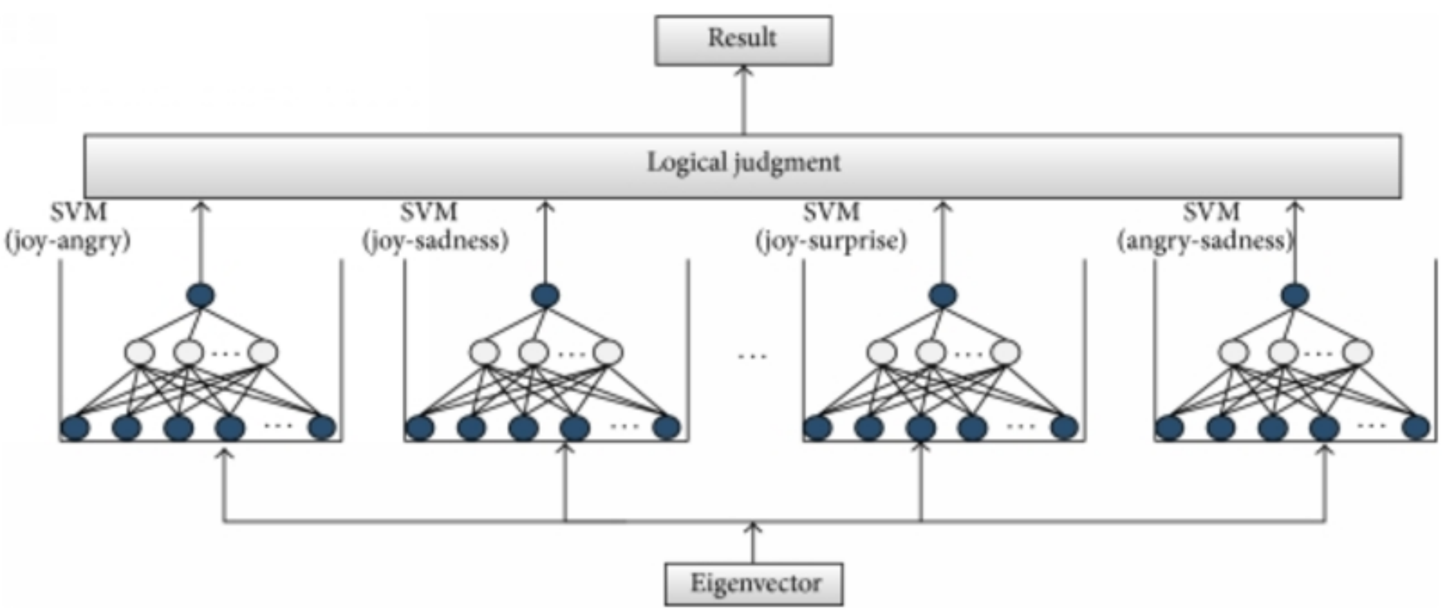
  Classifier classifies each frame in the video to one of the facial expression categories based on the tracking results of that frame.

  2. The Dynamic Approach

  These classifiers take into account the temporal pattern in displaying facial expression. A long video sequence will be separated into its different expression segments without sorting to empirical methods of segmentation.

Emotion Recognition System





Paralinguistic Speech Analysis

Prosody is the patterns of stress and intonation in a language. It can also refer to the patterns of rhythm and sound used in poetry.

Prosody is composed of

- Intonation
- Duration
- Intensity
- Speech quality

Voice quality is influenced by physiological factors

Feature Extraction

Extracting information from:

- Pitch contour: curve that tracks the perceived pitch of the sound over time
- Range, variance, mean, intensity
- Jitter and shimmer: measures of cycle-to-cycle variations of fundamental frequency and amplitude of voice
- Voice quality
- Duration: pauses, speaking rate
- Background information on speaker

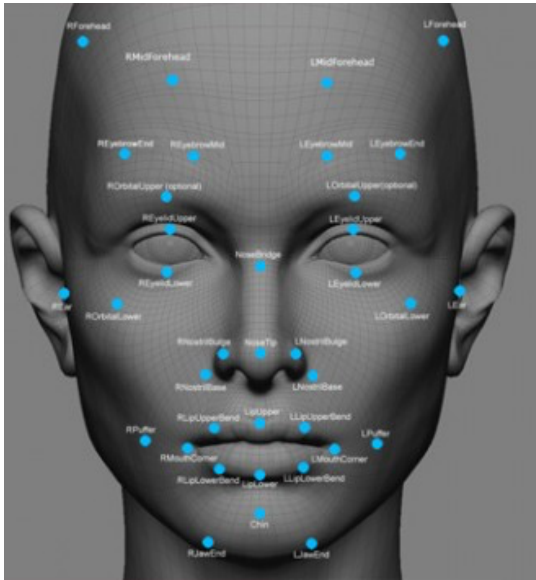
Emotional Facial Analysis

1. **Facial action coding system (FACS):**
   Taxonomy of human facial movements
   FACS is used to detect faces in videos, extract features geometrical features of the faces, and then produce temporal profiles of each facial movement.

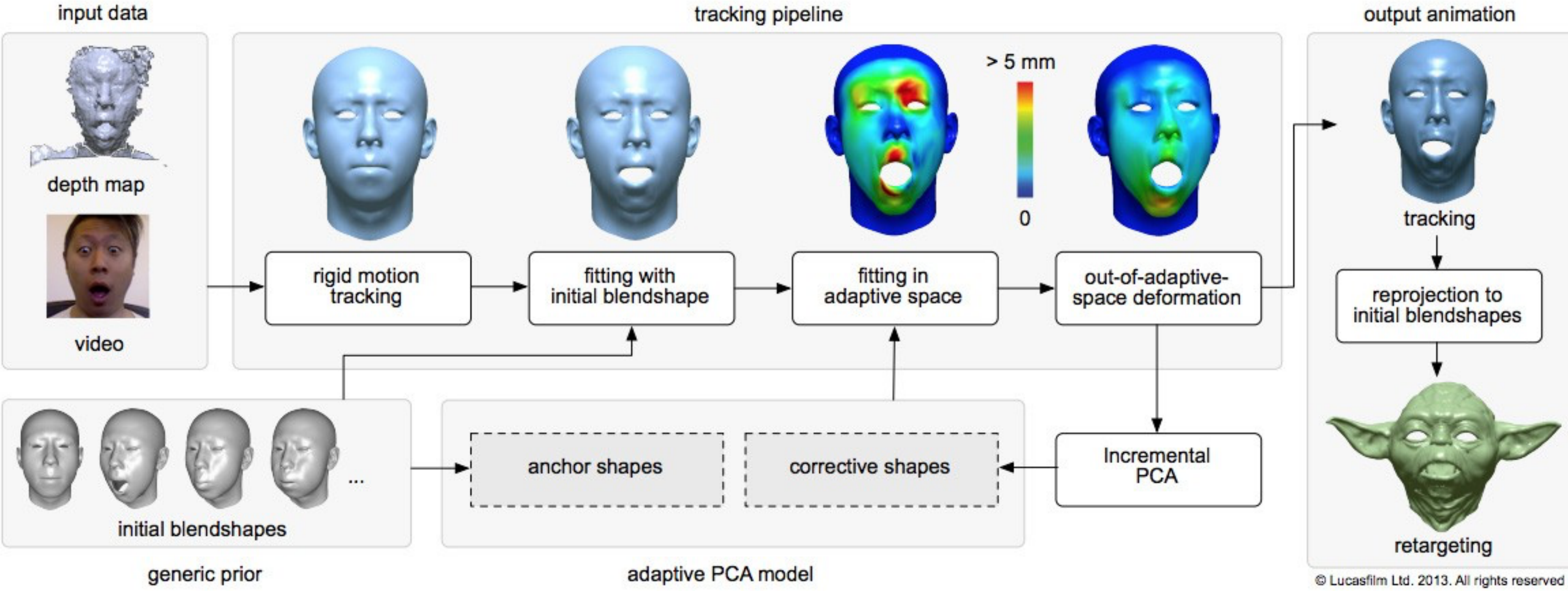
2. **Face animation parameter (FAP)**
   A standard for virtually representing humans and robots in a way that adequately achieves visual speech intelligibility as well as mood and gesture of the speaker

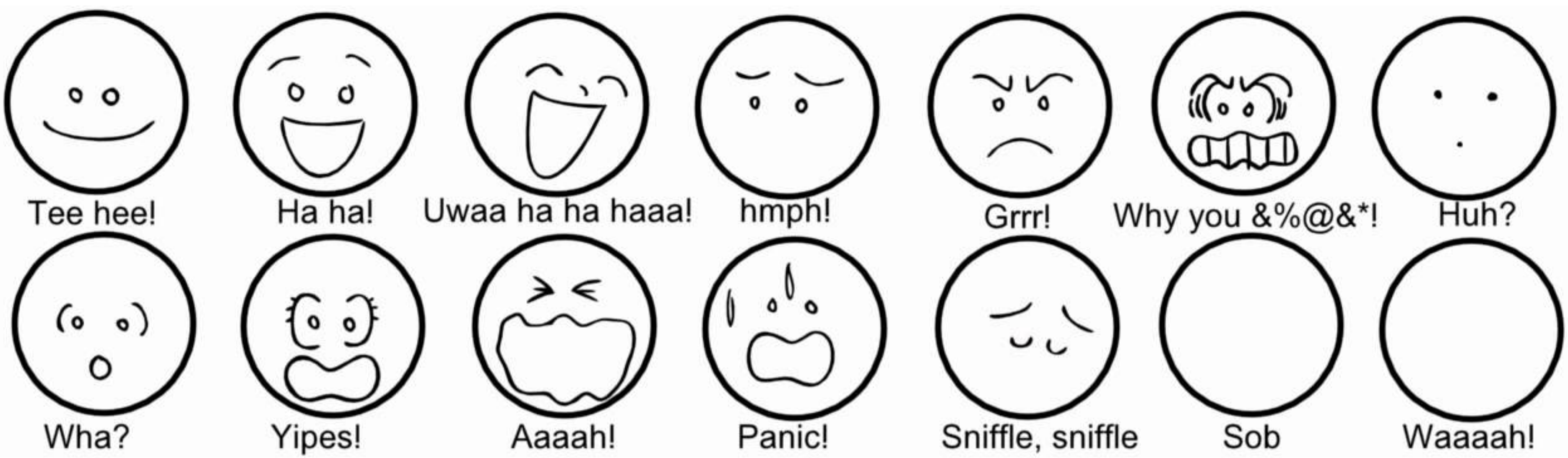
3. **Face definition parameter (FDP)**
   Control points that are used to define the shape of a proprietary face model

4. **MPEG-4 Standard**



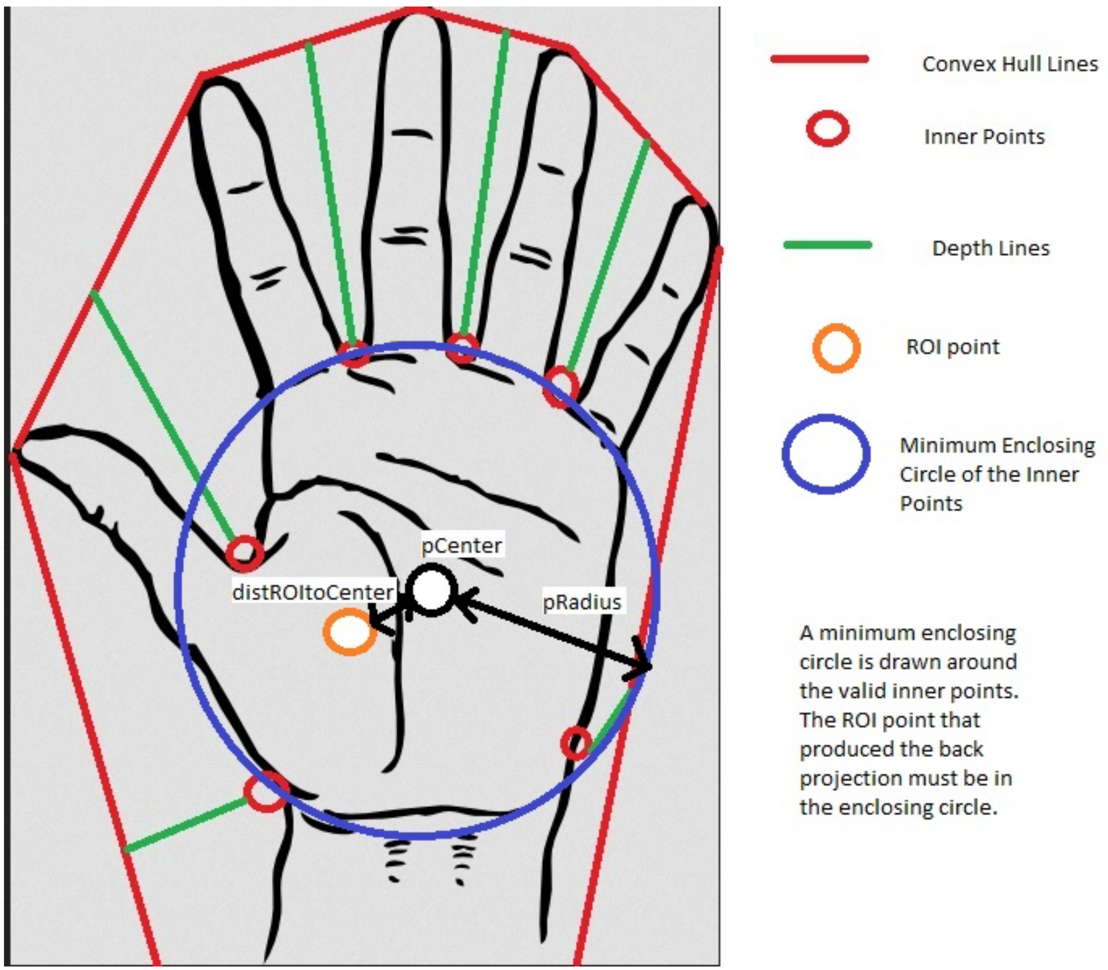
Facial Animation

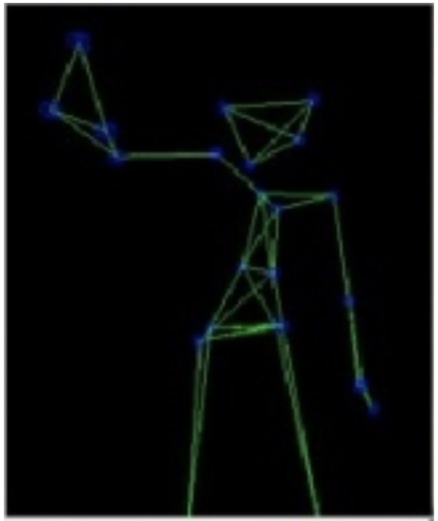




Emotional Gesture Analysis

- Hand tracking systems
- Tracking the centroid of skin masks
- Estimates of user's movement





Emotion Recognition Software

Targeting Emotion Recognition:

Facial animation parameter from the user’s face

Future merging of different emotional representations

Targeting Expressivity:

Facial expressivity

Time-varying facial movements

- Quantity and quality of movement
- Interaction
- Transition

Gesture expressivity

- Speed, acceleration, direction variation

Physiological Signal Analysis

Visceral differences between emotional states:

- Heart rate
- Skin conductance level
- Finger temperature
- Muscle activity

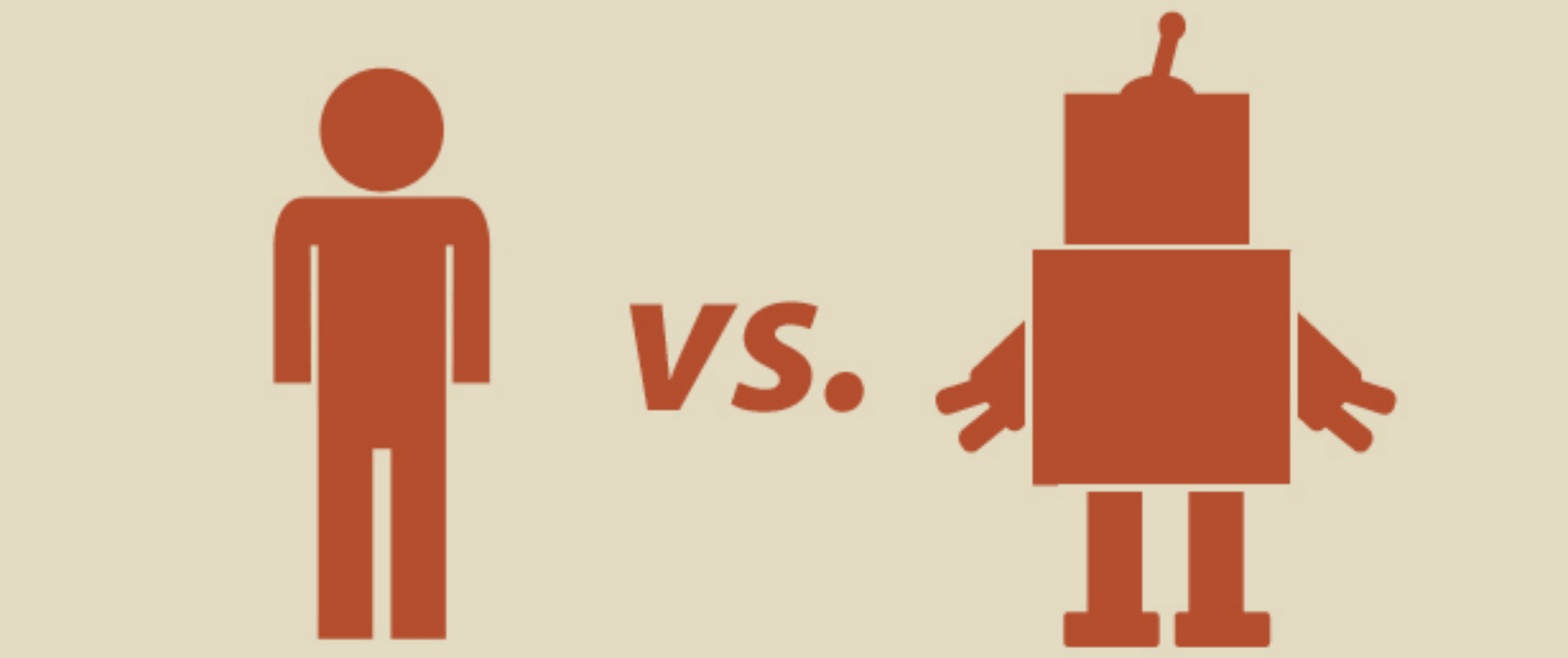
Measurement with physiologic information:

- Biosensor
- The value of skin conductivity
- Electromyography (EMG) sensors for muscle-activity

Multi-Modal Emotion Recognition

Define the processes and functions
- Visual, auditory, and physiological modalities

Identify different emotions in the recognition processes
Synchronization and temporal sequence in different modalities



Hiroshi Ishiguro

Social Robots

There are four classes of social robots:

1. **Socially Evocative**
   human-like
2. **Social Interface**
   natural interface by human-like social cues and communication modalities
3. **Socially Receptive**
   learning from interaction
4. **Sociable**
   pro-actively engaging with humans in order to satisfy internal social aims

Using Computers to Change What We Think and Do

Current robotics research focuses on building “human social” characteristics such as:
emotion, dialogue, relationship, natural communication, personality, and learning

Cue	**Example**
Physical	Face, eyes, body, movement
Psychological	Preferences, humor, personality, feelings, empathy
Language	Interactive language use, spoken language, language recognition
Social Dynamics	Taking turns, cooperation, praise for good work, answering questions, reciprocity
Social Roles	Doctor, teammate, opponent, teacher, pet, guide

Human-Computer Interactions

Test Your Understanding: Artificial Intelligence

What is the name for information sent from robot sensors to robot controllers?

A. Temperature
B. Pressure
C. Feedback
D. Signal
E. Output

Which of the basic parts of a robot unit would include the computer circuitry that could be programmed to determine what the robot would do?

A. Sensor
B. Controller
C. Arm
D. End Effector
E. Drive

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Android Robots

Android:
A robot designed to look and act like a human, with flesh-like resemblance

*Artificial intelligence is used to train robots to think and respond the way a human would. On left: **Android Erica** was developed by Japanese robotocist Hiroshi Ishiguro in 2015*

"My research question is to know what a human is. I use humanlike robots as test beds for my hypotheses" – hypotheses about human nature, intelligence, and behavior (Ishiguro of Osaka University)

Android Erica

Applications of Android Robots

Hiroshi Ishiguro built an android robot of his four year old daughter for her birthday
Example of Uncanny Valley

1. Robot as a ***persuasive machine*** to ***change*** the behavior, feelings, or attitudes of humans

2. Robot as an ***avatar,*** *which is a* ***representation of*** *or* ***representation for*** *the human*

Robots with social skills can:
- develop interactions themselves
- support a wide range of users
- can be a part of an individual's life

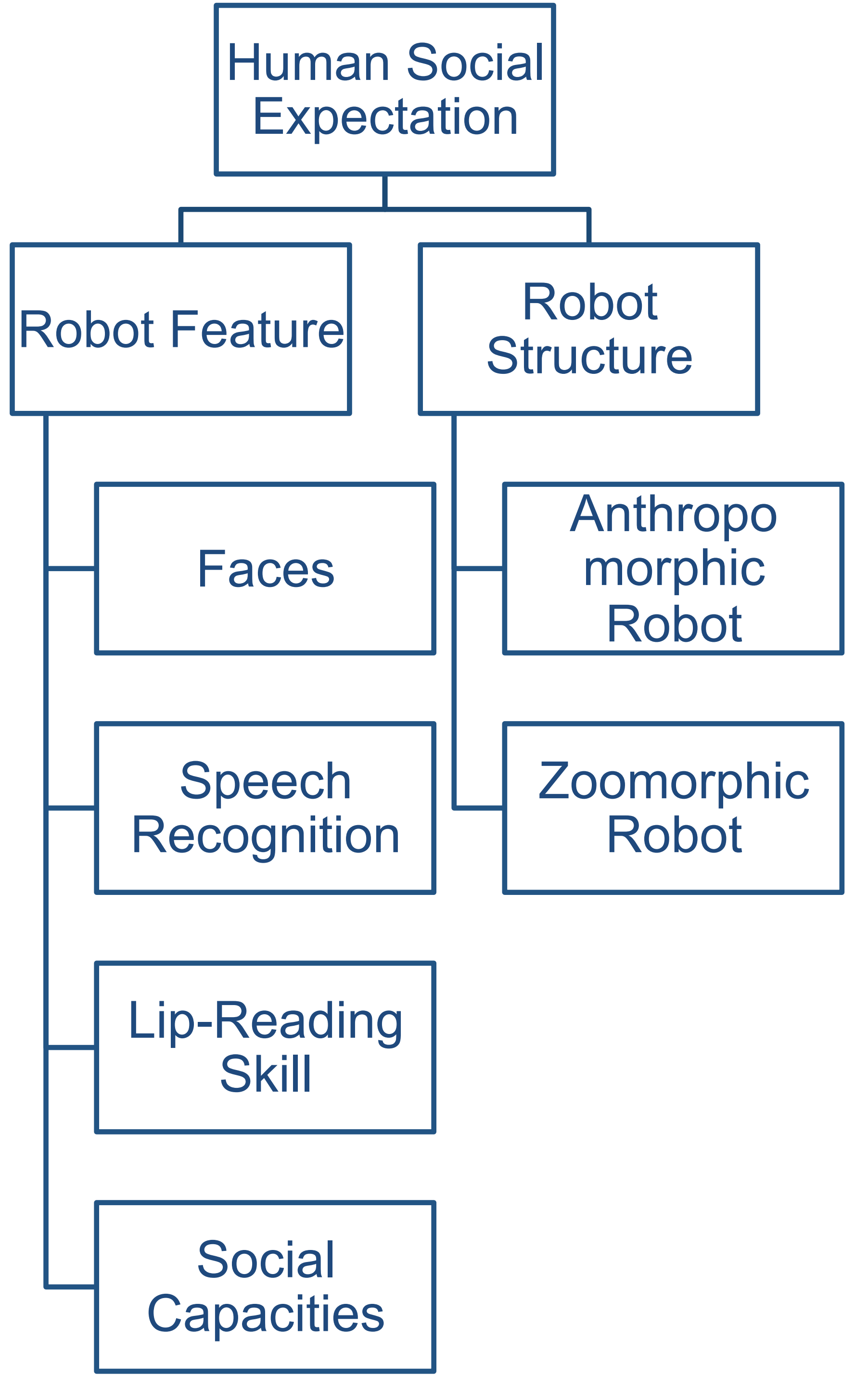
Justification of Android Robots:
A machine with human-like form may have more human-like interactions with people

Social Robot Design

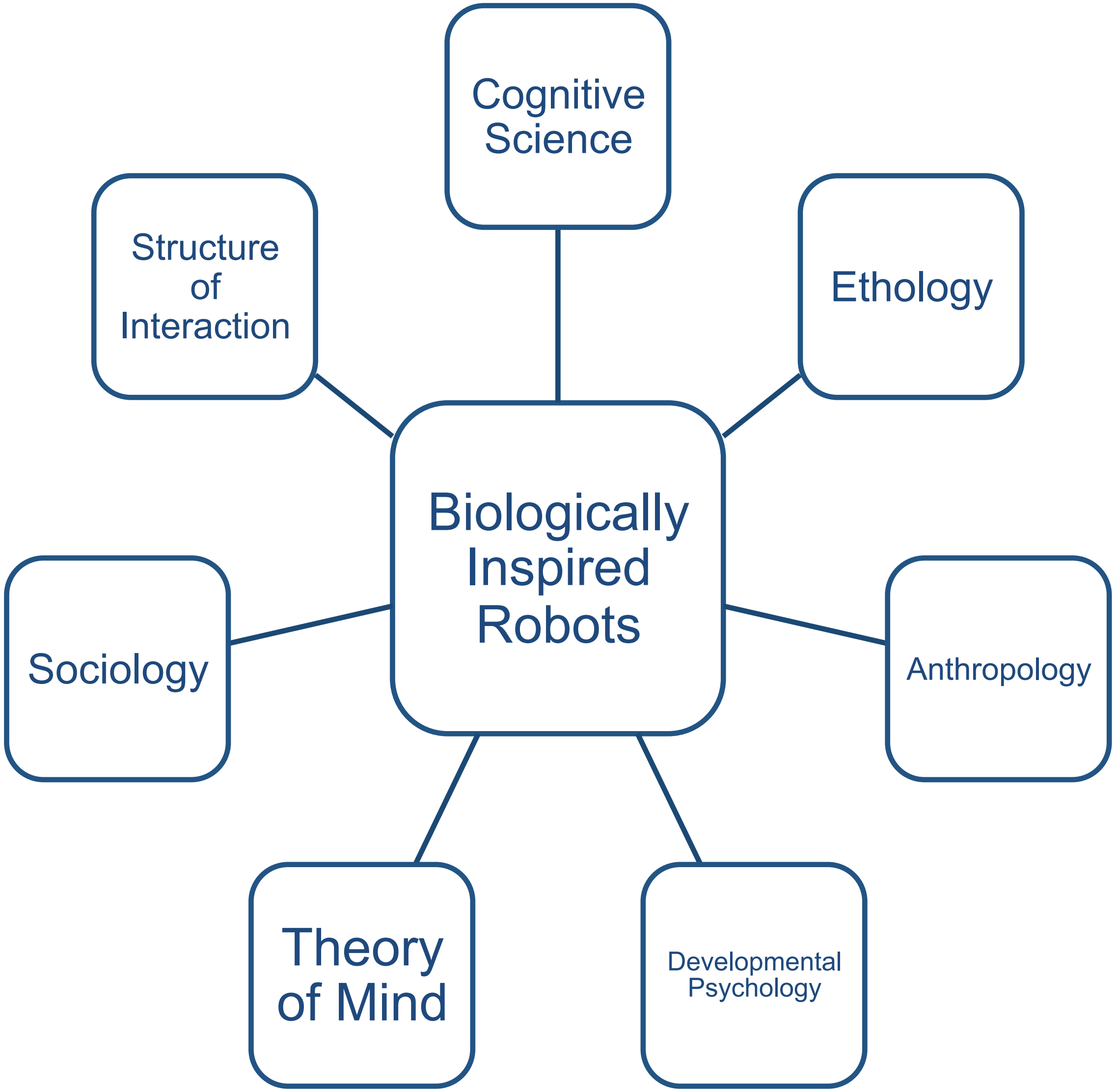
Human social expectations include: enjoyment, empowerment, and competency

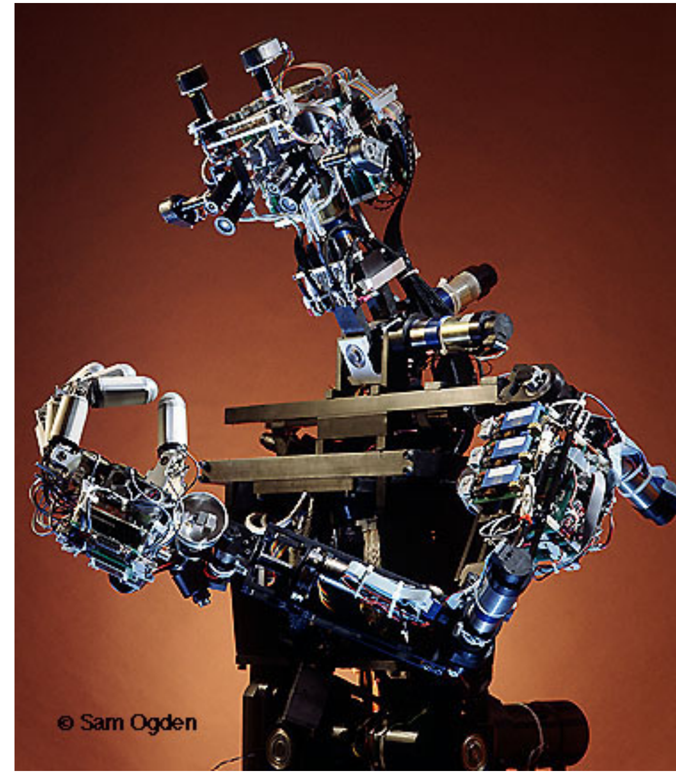
How are socially interactive robots built?

1. Biologically-inspired robot
   Social Intelligence and Socially Interactive
2. Functionally-designed robot
   Socially Interactive and Functionally Structured



Biologically Inspired Robots





Cog (MIT):
Project at Humanoid Robotics Group
Idea: Human-level intelligence requires interacting with humans

Functionally Designed Robots

1. Constrained operational and performance objectives
   i.e. a restaurant robot can do greetings, serving, and cleaning
2. Certain effects and experiences with the user
   i.e. greetings: joy
   serving: happiness
   mistake: sadness

DyRos (Dynamic Robot System) Humanoid Robot:
DyRos was 3-D printed in full. It was a collaborative effort of two South Korean institutes: Digital Human Research Center and Dynamic Robot Systems Lab. The top half is in progress.

Functionally Designed Robots

Motivations for Functional Design:

1. Physical Limitation
   - short-term interaction
   - limited quality of interaction
   - limited embodiment and capability of a robot
   - constraint by the environment
2. Effects of Functional Design
   - affordances (action possibilities) and usability can be improved even with the limited social expression
     i.e. recorded or scripted speech
   - artificial designs can provide compelling interactions for entertainment
     i.e. video games and electronic toys

Principles of Traditional Robot Design

Traditional Robots:

1. Cognition: planning and decision-making
2. Environment sensing and navigation
3. Actuation: mobility and manipulation
4. Interface: inputs and display
5. System Dynamics: control architecture and electro-mechanics

Factors that affect impact and acceptance of a robot design:

1. Morphology
   - physical form influences desirability, expressiveness and accessibility of a robot
2. Anthropomorphic
   - Superior peer interactions
   - Balance of visual illusion and interactive functionality
3. Zoomorphic
   - Entertainment robots as toys
   - Expectations are lower

Principles of Social Robot Design

Social Robots:

1. **Human oriented perception**
   - detecting and organizing gestures
   - monitoring and classifying activity
   - discerning intent
   - measuring feedback from human peers
2. **Natural Human-Robot Interaction**
   - believable behavior
   - following social norms
3. **Readable Social Cues**
   - useful for expression and easy interaction
   - gestures and voice recognition
4. **Real-Time Performance**
   - operate at human interaction rates

- If meant to do tasks for a human, robot should look closer to a product.
- If meant for peer interaction, robot should look closer to a human.
- A considerable amount of robot qualities should be maintained as to prevent excess confidence in the robot's abilities
- A specific amount of familiarity should exist

Test Your Understanding: Robot Design

Which of the following terms is **not** one of the five basic parts of a robot?

A. Peripheral tools
B. Effectors
C. Controller
D. Drive
E. Sensor

The number of moveable joints in the base, the arm, and the end of the effectors of the robot determines:

A. Payload Capacity
B. Operational Limits
C. Flexibility
D. Degrees of Freedom
E. Cost

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Applications of Emotion Recognition

1. **Medicine**
   Aiding elderly patients with rehabilitation
   Companion for autistic children
2. **Online Tutoring**
   More interactive and effective to provide feedback
3. **Monitoring**
   ATM not dispensing when client scared
   Prioritize angry calls in service center
4. **Entertainment**
   Music player that recognizes mood and emotions of users
5. **Marketing**
   Emotions vital in purchasing decisions
   Can study attention and engagement of users to improve sales

Next Time:
Artificial Intelligence in Robotics

How to Build Baymax
Deep Learning