# Applied Neuroscience

**Columbia Science Honors Program**

**Fall 2017**

***Artificial Intelligence*** *and* ***Sensory Systems***

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PLoS COMPUTATIONAL BIOLOGY

# One Rule to Grow Them All: A General Theory of Neuronal Branching and Its Practical Application

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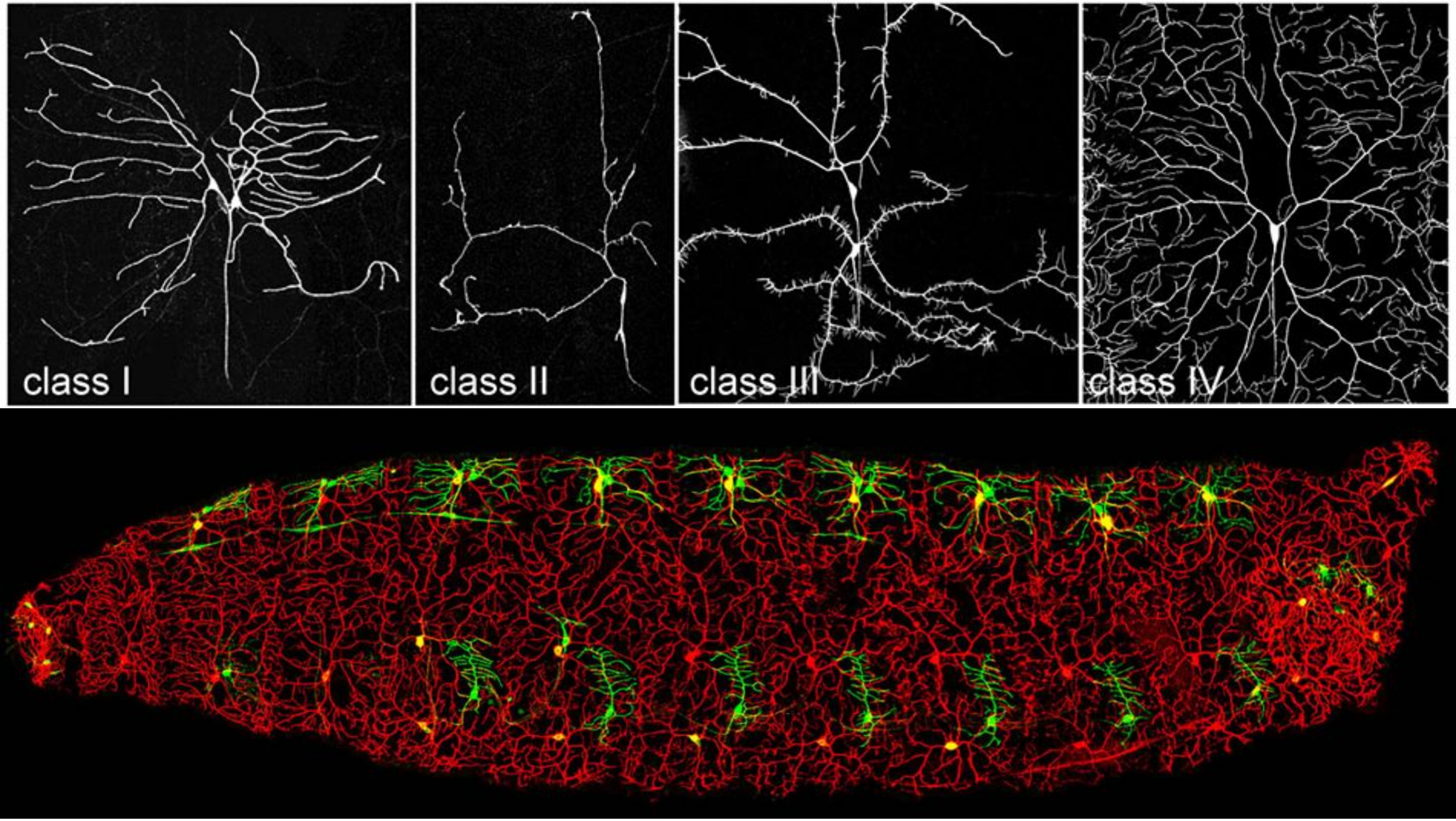
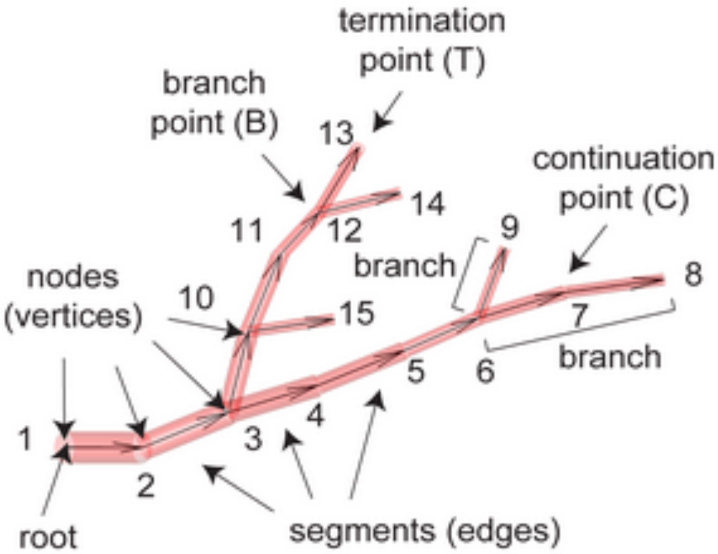
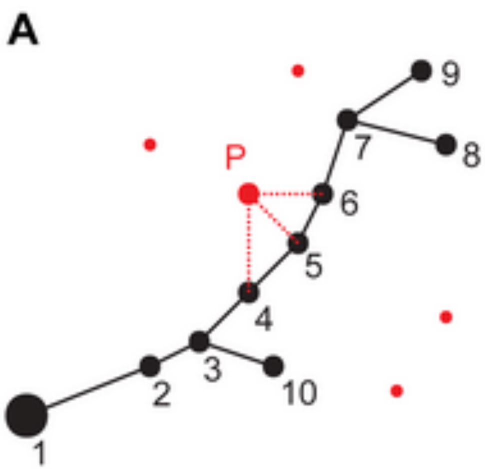
*Cuntz et al* model neurons based on axonal and dendritic branching patterns

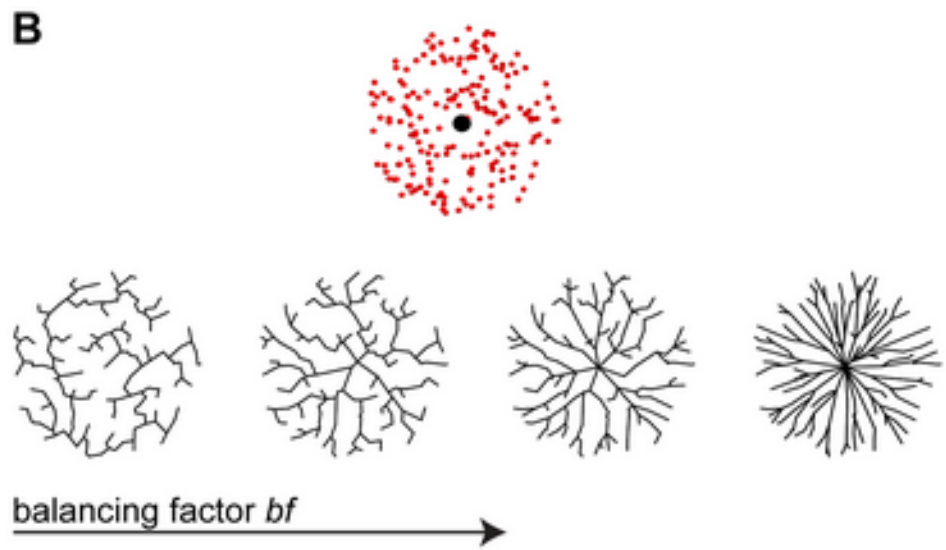
- Represent dendritic arborizations as locally optimized graphs
- Extract order from neuroanatomical complexity based on optimization of
  - Space
    - A neuron's precise branching morphology is important in determining its electrophysiological properties
  - Cytoplasm
    - Fluid that defines electrical properties of neuronal axon
  - Conduction time in neural circuitry
    - Determines function and direction of signal flow in the brain

# Diverse dendrite morphology of da neurons



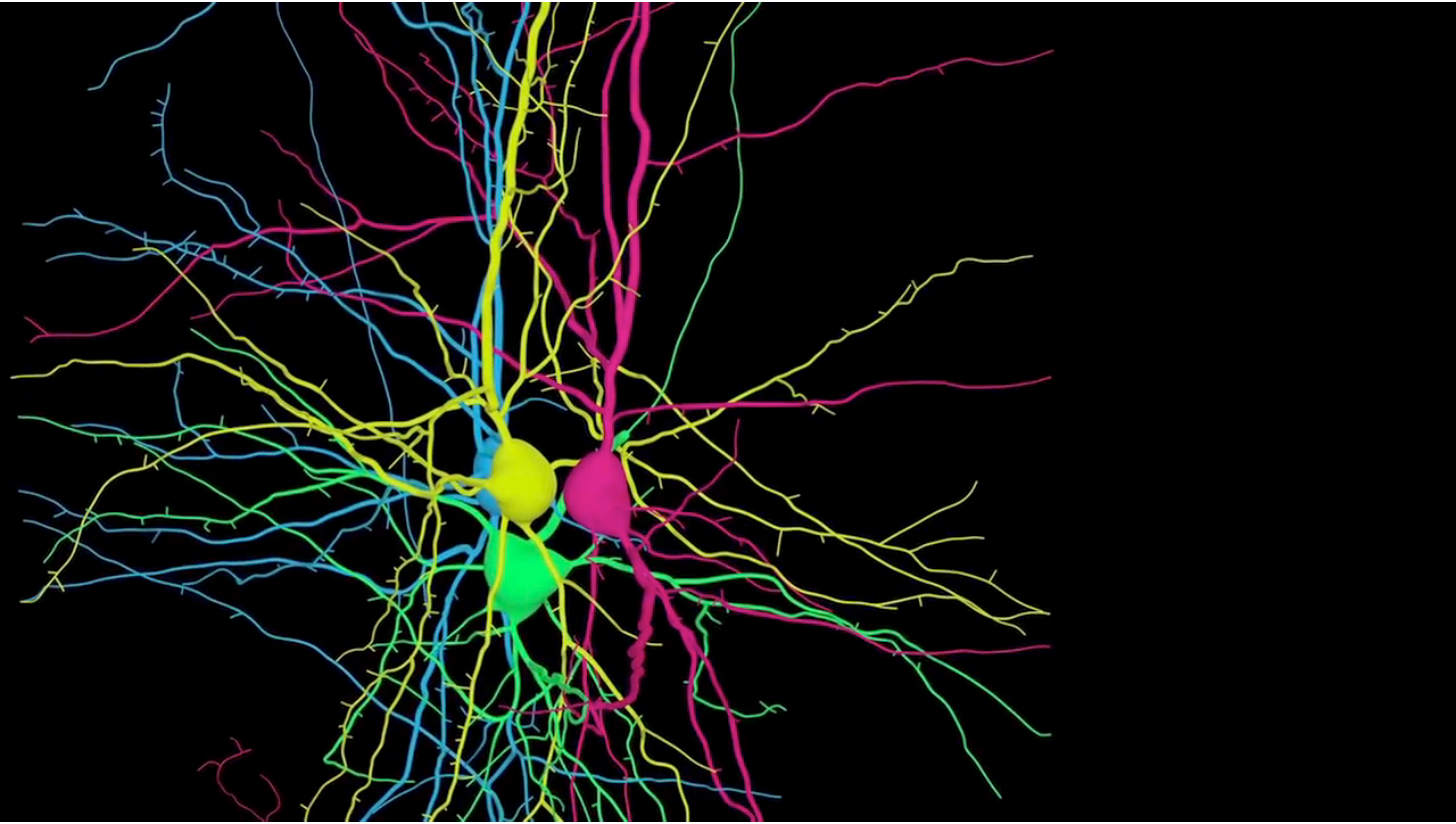



*Cuntz et al, 2010*

# Computational Neuroanatomy



# Artificial Emotion in Robots

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

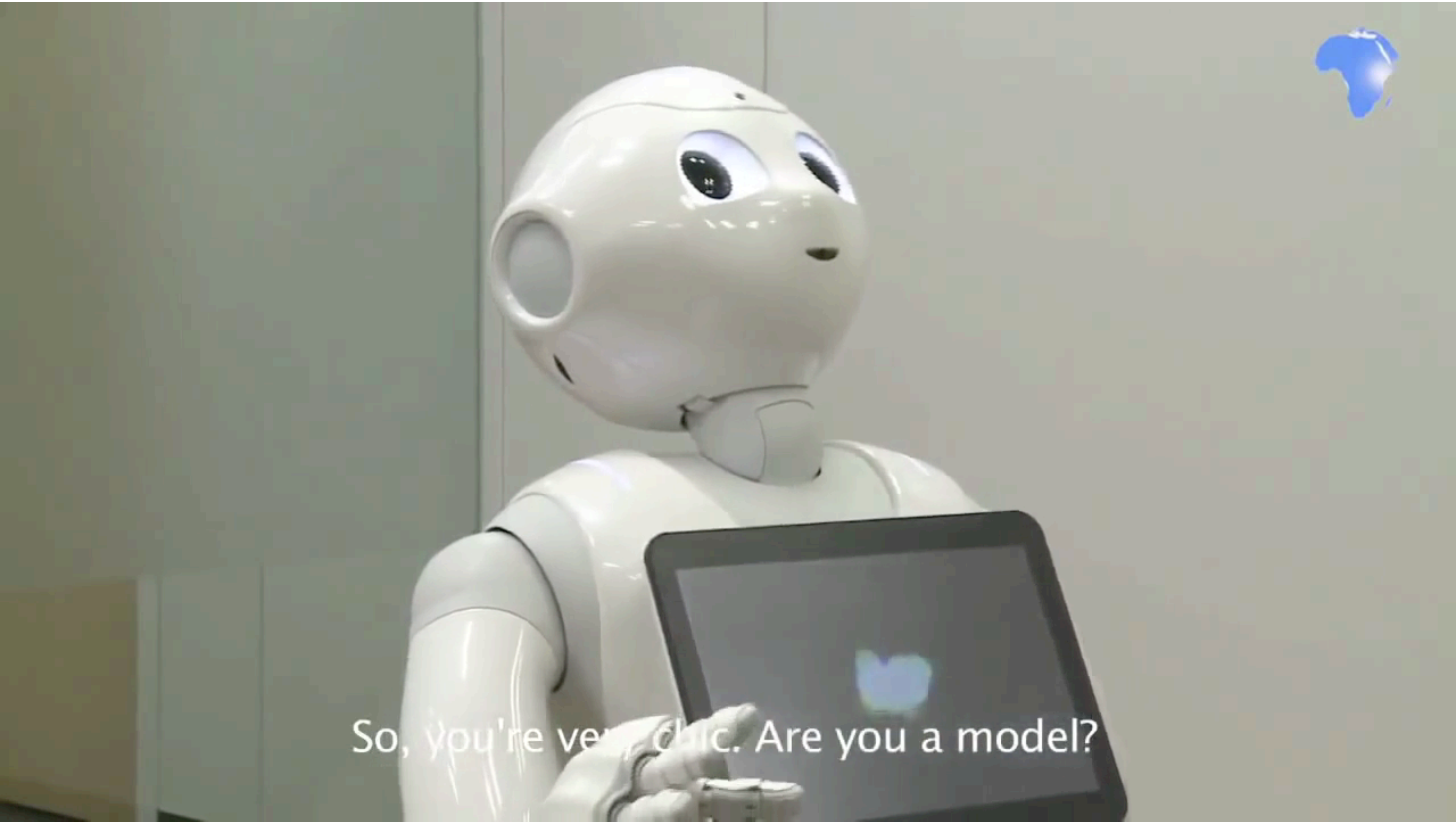
**Artificial emotion used in social robots**

- 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

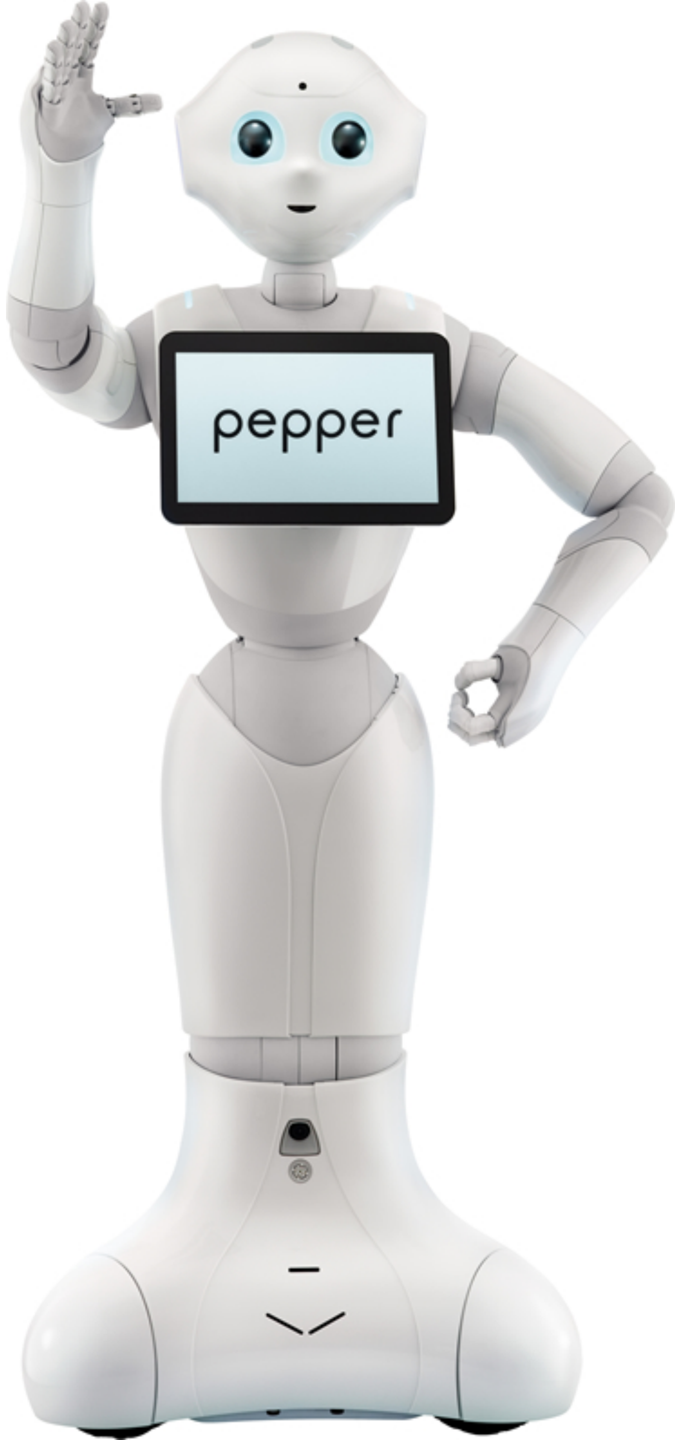
**Vision:** 2 HD cameras and 1 3D camera in Pepper's head, which allows him to identify movements, objects, and faces with enough detail to recognize emotions

**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

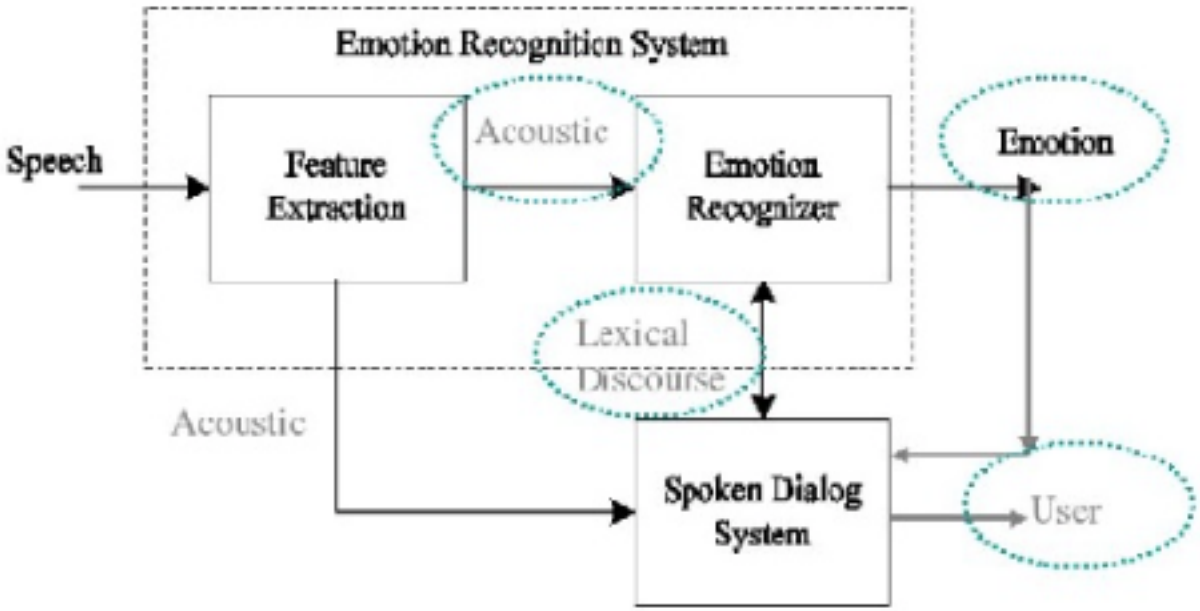
  **1. The Static Approach**

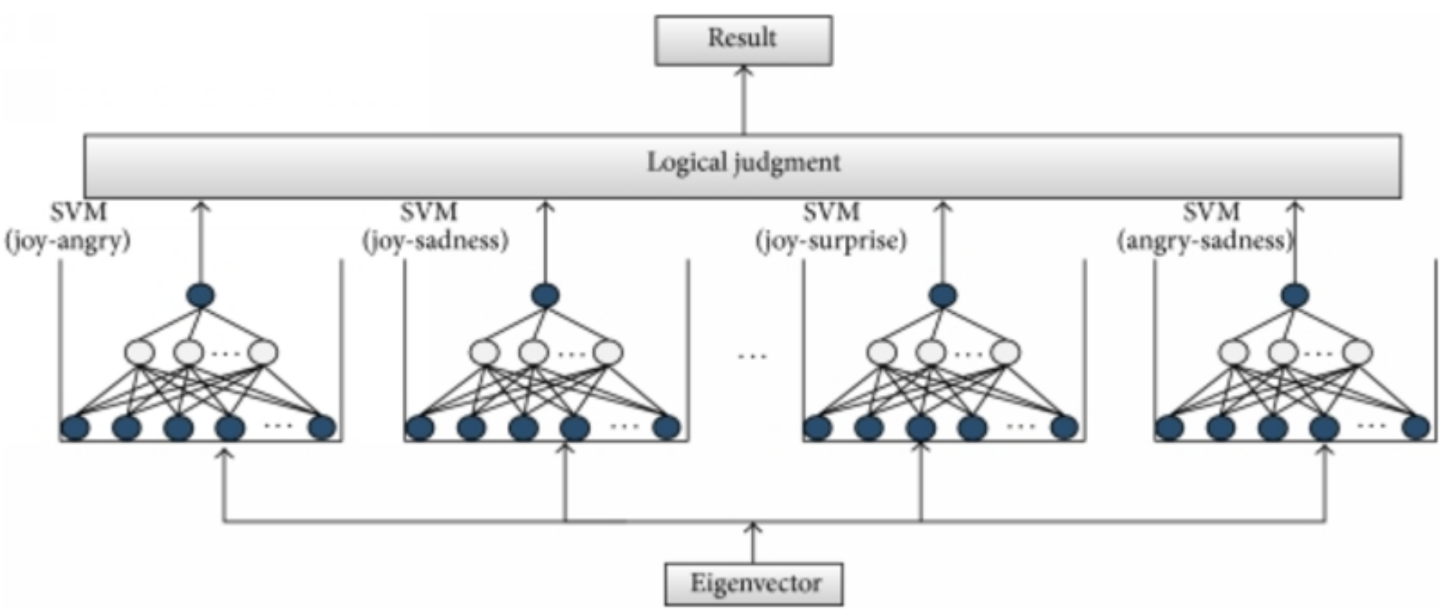
  Classifier classifies each frame in the video to one of the facial expression categories based on the tracking results of that frame.

  **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

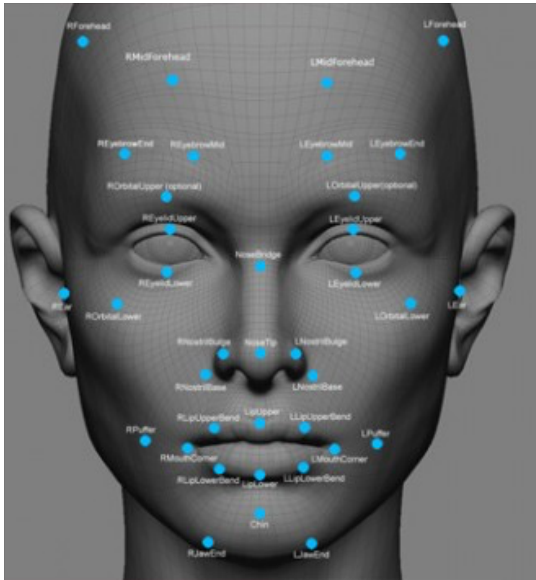
# Emotional Facial Analysis

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.*

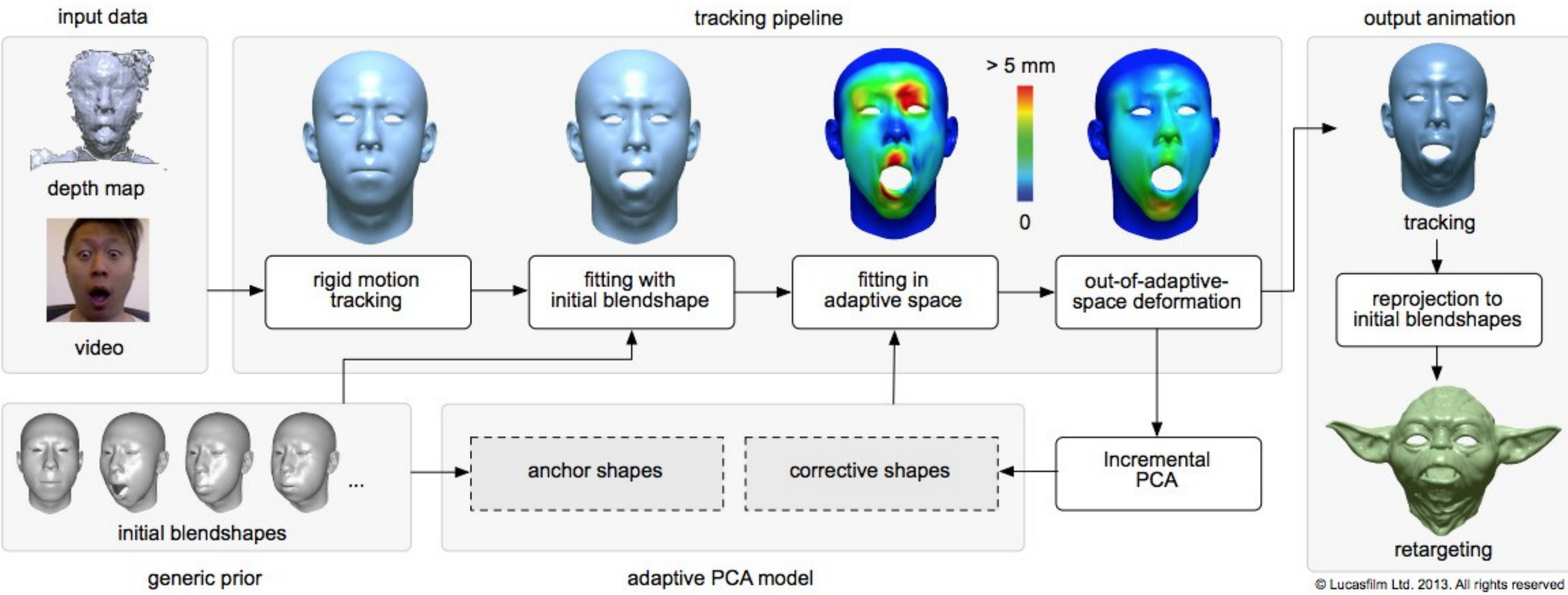
2. **Face animation parameter (FAP)**
   A standard for virtually representing humans and robots in a way that adequately achieves visual speech intelligibility as well as mood and gesture of the speaker

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

4. **MPEG-4 Standard**

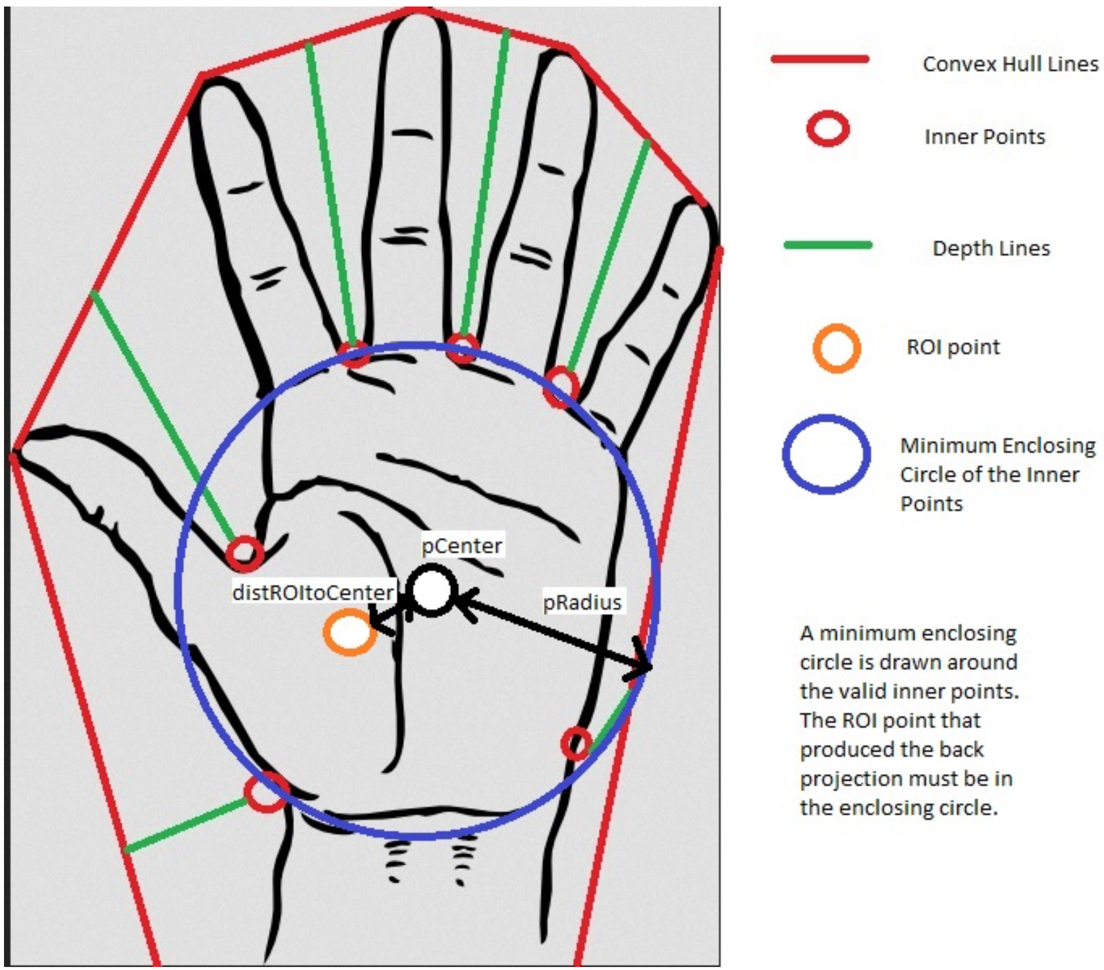


# Facial Animation




# 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

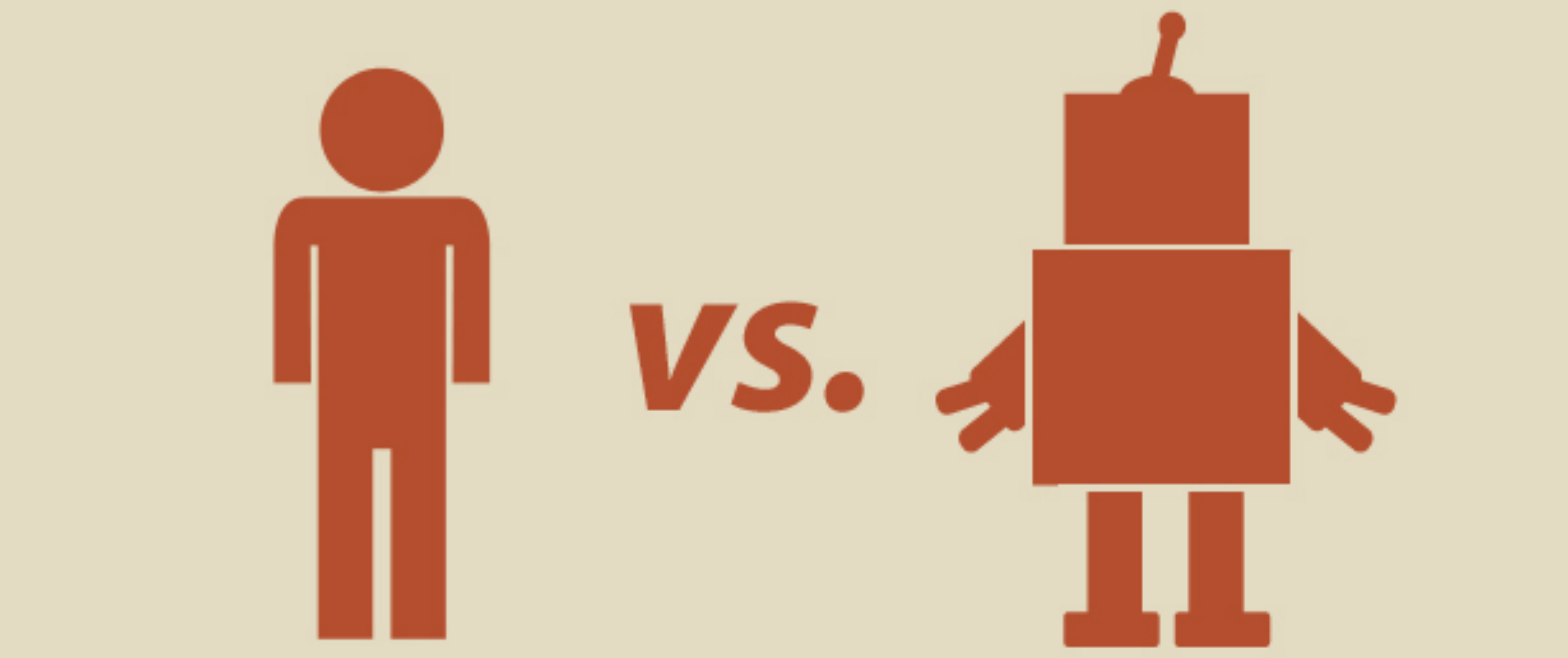
# Multi-Modal Emotion Recognition

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

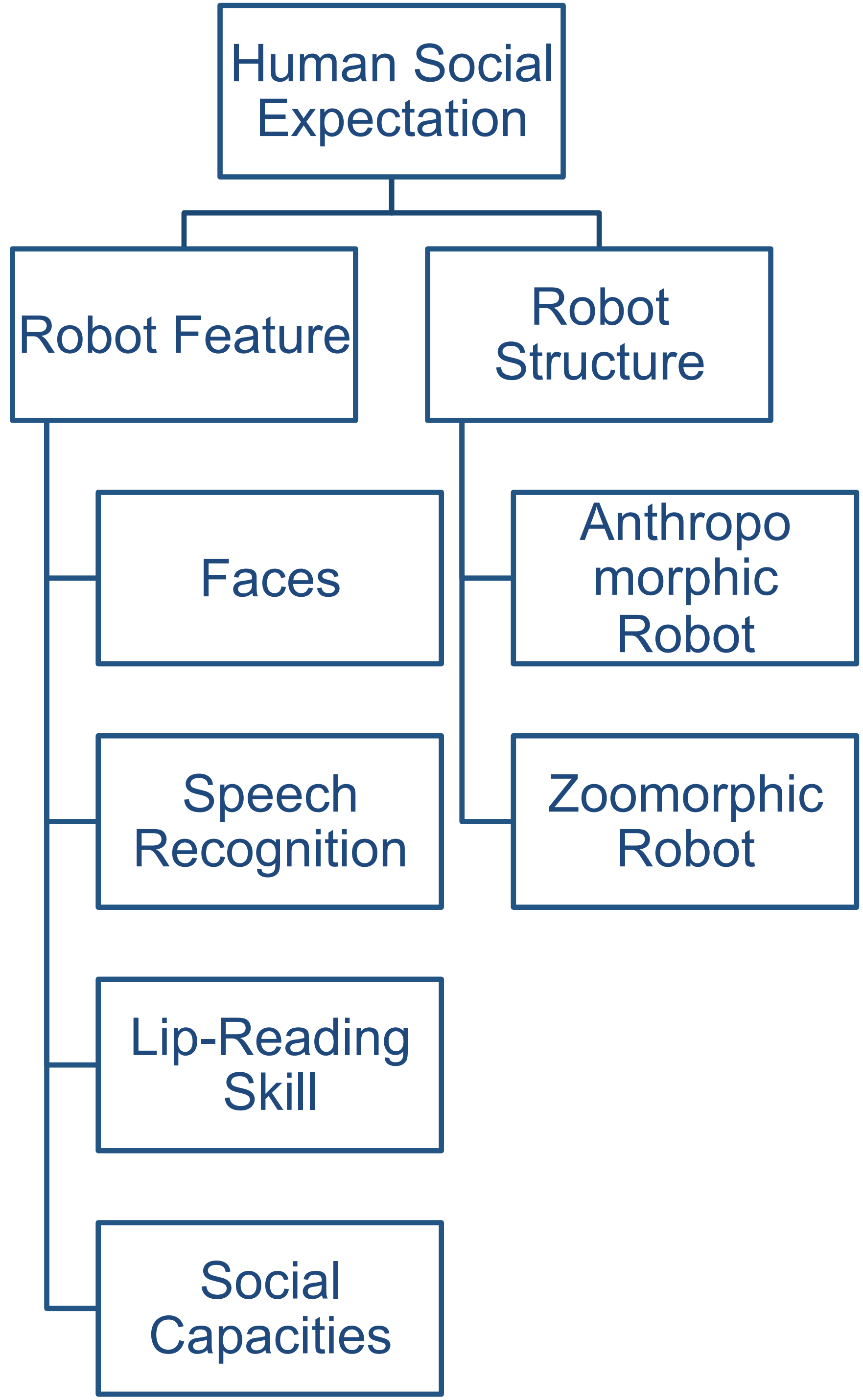
**Justification of Android Robots:**
*A machine with human-like form may have more human-like interactions with people*

# Social Robot Design

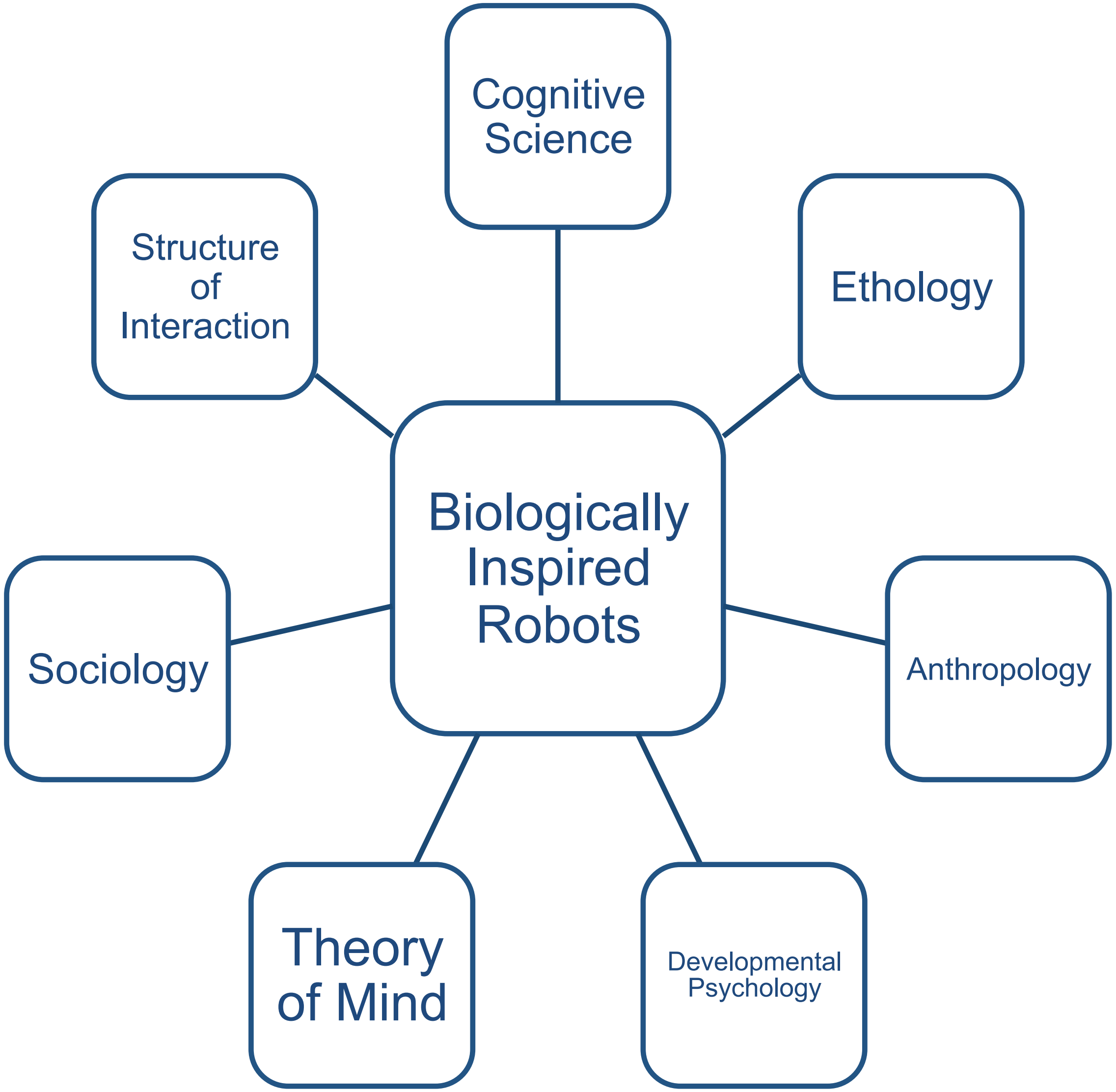
Human social expectations include: enjoyment, empowerment, and competency

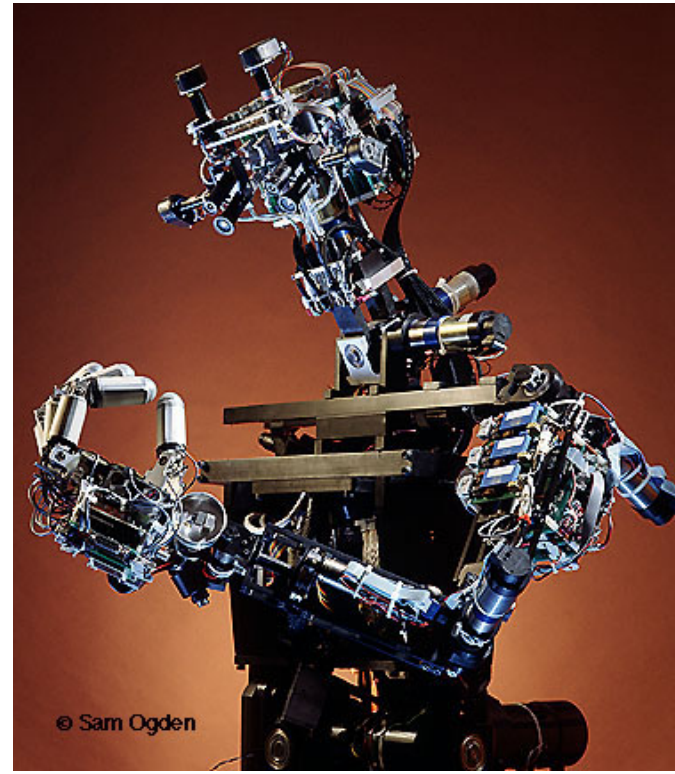
*How are socially interactive robots built?*

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

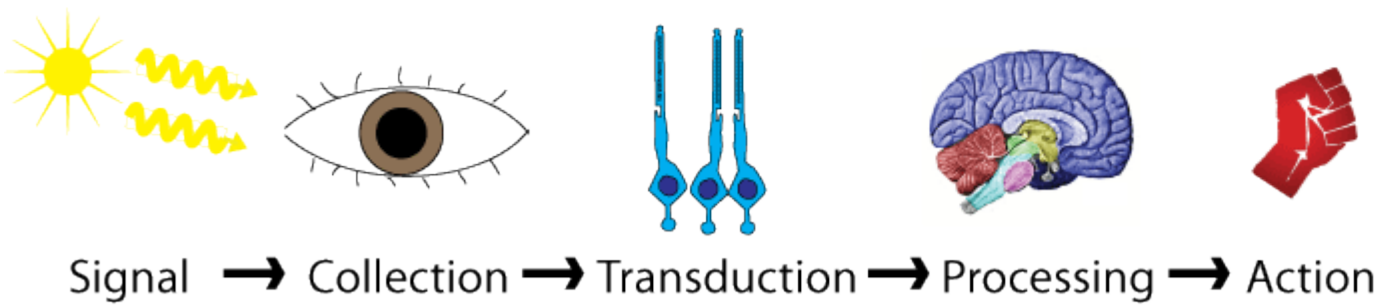
# Sensory Systems

## How do sensory systems work?

Neurons in sensory regions of the brain respond to stimuli by firing action potentials after receiving a stimulus.

Each sensory system follows a specific plan:

1. **Reception:** Stimulus molecules attach to receptors.
2. **Transduction:** Receptors convert the energy of a chemical reaction into action potentials.
3. **Coding:** The spatial and temporal pattern of nerve impulses represents the stimulus in a meaningful way.



# Chemical Senses

Sensory systems associated with the nose and mouth (olfaction and taste) detect chemicals in the environment.

**Gustatory System**: detects ingested, primarily water-soluble, molecules called *tastants*
**Olfactory System**: detects airborne molecules called odors

These systems rely on receptors in the nasal cavity, mouth or face that interact with the relevant molecules and generate action potentials.

# Functions of Olfaction

- Many animals are *macrosmatic*
  - ❖ A keen sense of smell is necessary for survival
- Humans are *microsmatic*
  - ❖ A less keen sense of smell that is not crucial to survive

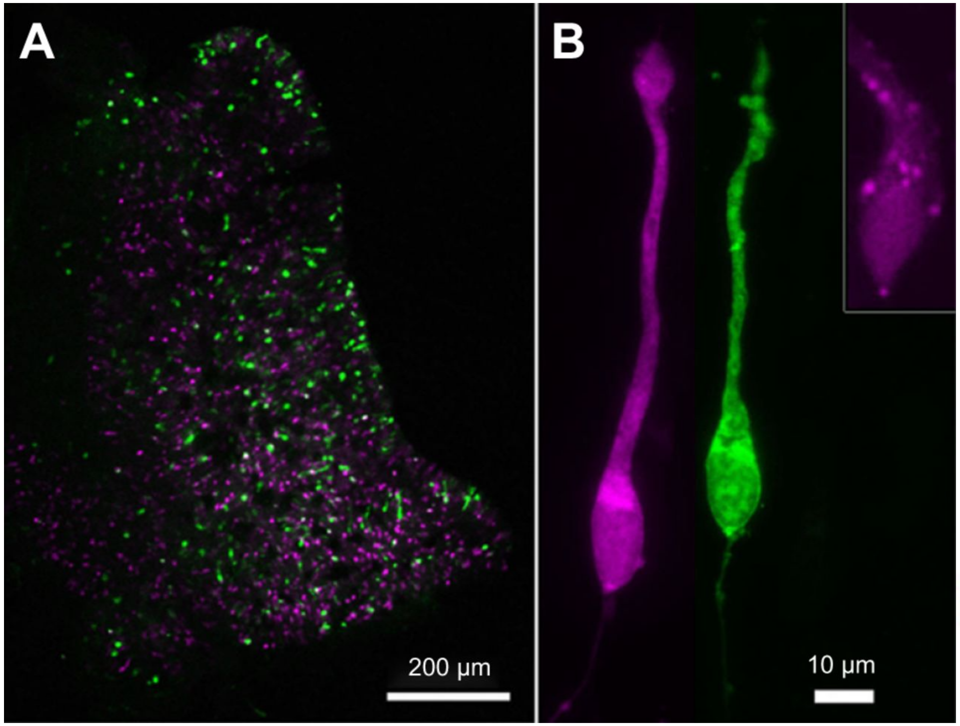
- Rats are 8 to 50 times more sensitive to odors than humans
- Dogs are 300 to 10,000 times more sensitive than humans

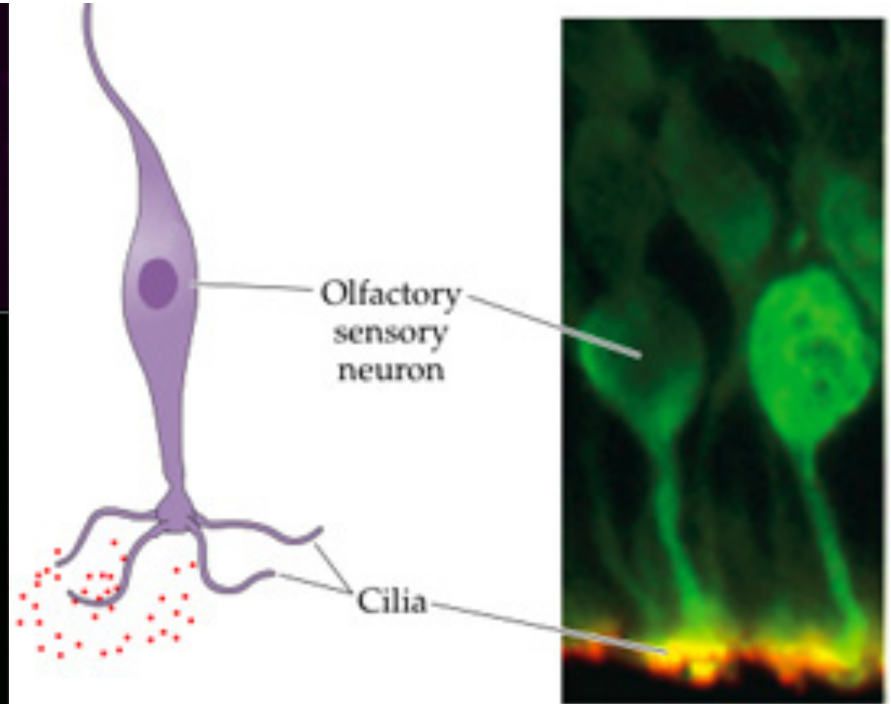
**Why does this difference exist?**

*The difference lies in the number of receptors they each have. Humans have 10 million while dogs have 1 billion olfactory receptors.*

# Richard Axel on Olfaction

# Olfactory System




Olfactory sensory neurons have a single dendrite that projects down to the mucus:

- Terminal ending of dendrites have 5-25 cilia
- Each cilia has up to 40 GPCRs
- In lower animals, many more GPCRs are present (increased density of receptors)

# Gustatory System

**Objective:** Understand how the gustatory system works

**Agenda:**

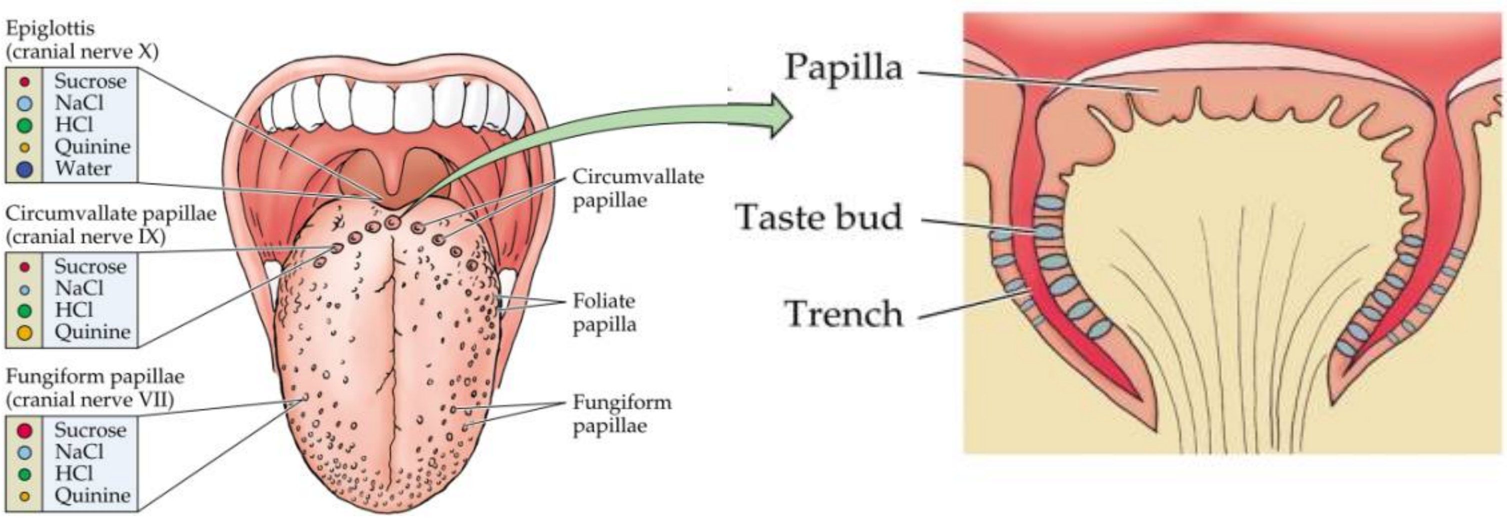
1. Morphology of Cells
2. Gustatory Pathway

    Miracle Berries Demo

# Gustatory System

## Morphology of taste buds and cell types:

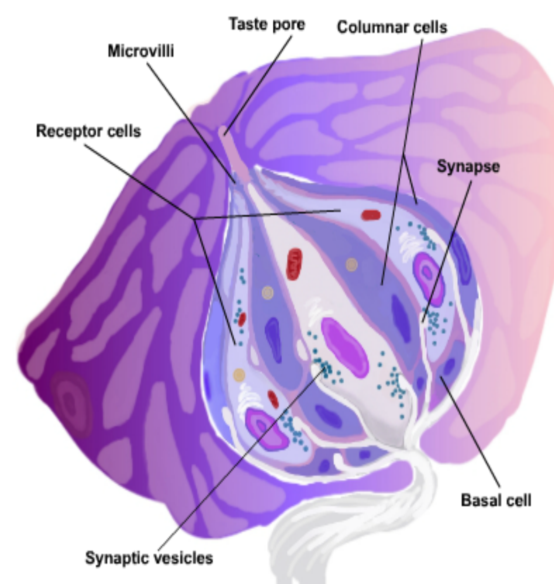
- Taste buds are located on papillae and are distributed across the tongue
- They are also found on the oral mucosa of the palate and epiglottis
- Taste buds contain 80 cells arranged around a central taste pore.



# Gustatory System

## Taste receptor cells:

- Spindle shaped cells that extend from the base to the apex of taste buds
- Taste solutes are transported to the taste pore and diffuse through the fluid layer to make contact with membrane receptor proteins on the microvilli and apical membrane
- Taste sensitivity is dependent on the concentration of taste molecules and their solubility in saliva



# Gustatory System

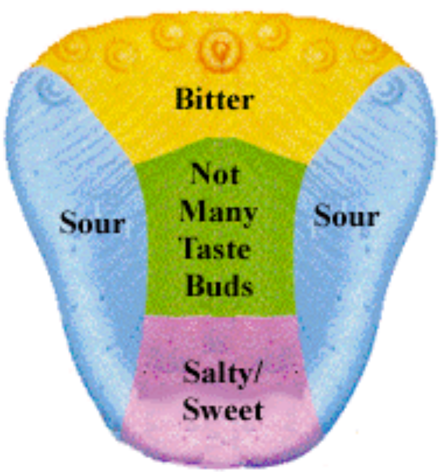
## Sensory Transduction:

- Taste sensation can be caused by diverse *tastants*
- Action potentials in the taste receptor cells leads to an increase in $Ca^{2+}$ influx through voltage-gated channels with a release of $Ca^{2+}$ from intracellular stores
- In response to $Ca^{2+}$, neurotransmitter is released, which causes synaptic potentials in the dendrites of the sensory nerves and action potentials in the afferent nerve fibers

# Gustatory System

## Taste distribution:

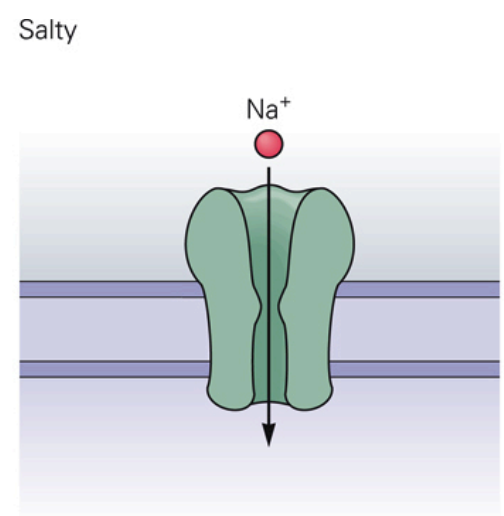
- Most of the tongue is receptive to all basic tastes
- There are certain regions that are most sensitive to a given taste
  - Bitter: across back of tongue
  - Sour: on side closest to the back
  - Salty: on side more rostral than sour
  - Sweet: across front of tongue




# Gustatory System

## How is salt processed?

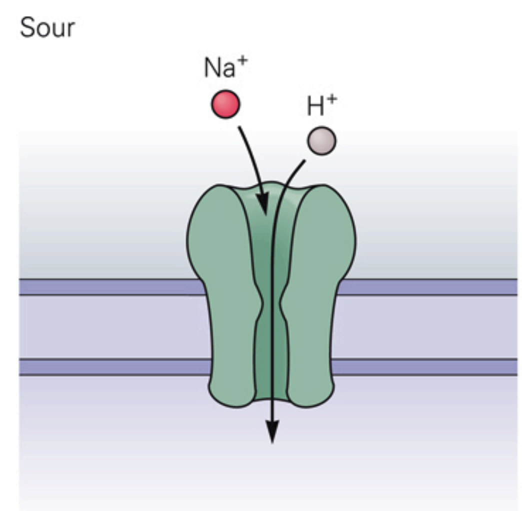
- $Na^+$ flows down a concentration gradient into the taste receptor cell
- $Na^+$ increases within the cell, which depolarizes the membrane and opens a voltage dependent $Ca^{2+}$ channel
- $Ca^{2+}$ increase causes the release of neurotransmitters



# Gustatory System

**How are acids (<u>sour</u> tastants) processed?**

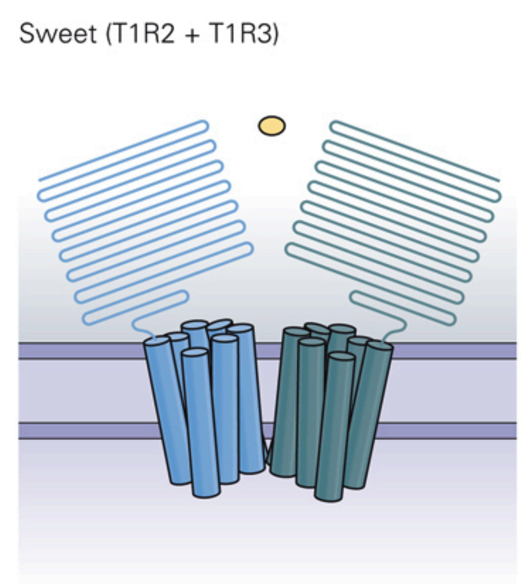
- Foods that are sour have high acidity (low pH)
  - When acids are dissolved in water, they generate $H^+$ ions
- $H^+$ ions pass through the same channel that $Na^+$ does
- $H^+$ blocks a $K^+$ channel as well
- The net movement of cations into the cell depolarizes the taste cell
  - This opens a $Ca^{2+}$ channel
  - It causes neurotransmitter release



# Gustatory System

## How is sweet processed?

- Molecules that are sweet bind to specific receptor sites and activate a cascade of 2nd messengers in certain taste cells
- These molecules also bind to receptors
- G-protein activates an effector enzyme-adenylate cyclase and produces cAMP
- cAMP causes a $K^+$ channel to be blocked
- The cell depolarizes
- $Ca^{2+}$ channel opens and $Ca^{2+}$ enters the cell
- Neurotransmitter is released



# Gustatory System

## How is bitter processed?

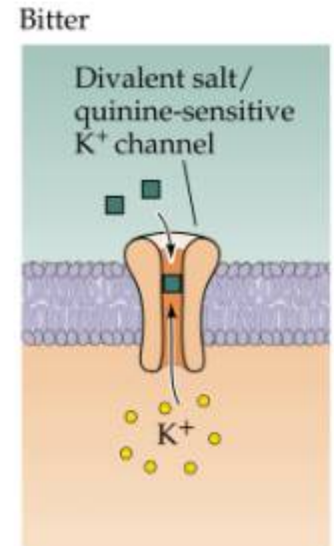
- Noxious chemicals in the environment are often bitter
  - Senses have evolved to protect and preserve
  - The ability to detect bitter has two separate mechanisms

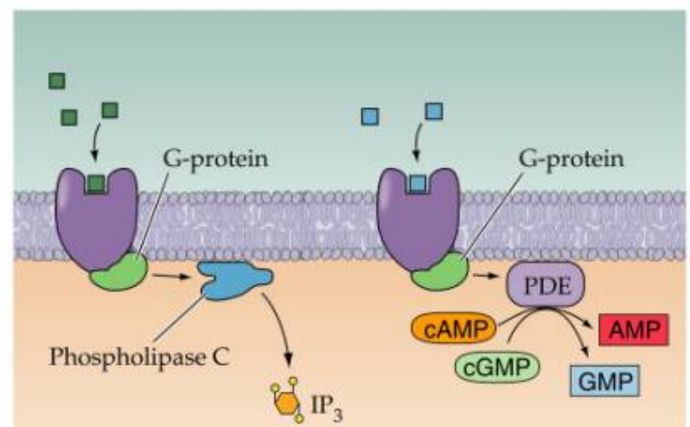
System 1:

- Bitter tastants can directly block a K+ channel
- Cell depolarizes
- Ca2+ channel opens and Ca2+ floods in
- Neurotransmitter is released

System 2:

- Bitter tastants bind to bitter receptor
- G-protein activates an effector enzyme
- Ca2+ is released from extracellular storage
- Ca2+ increase causes neurotransmitter release

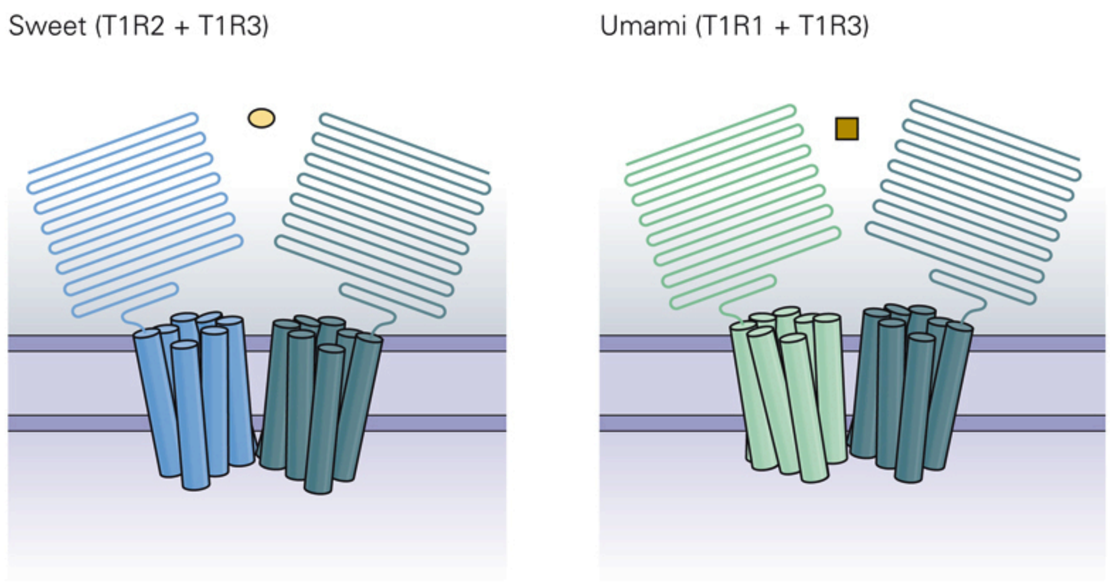


# Gustatory System

## How is <u>umami</u> processed?

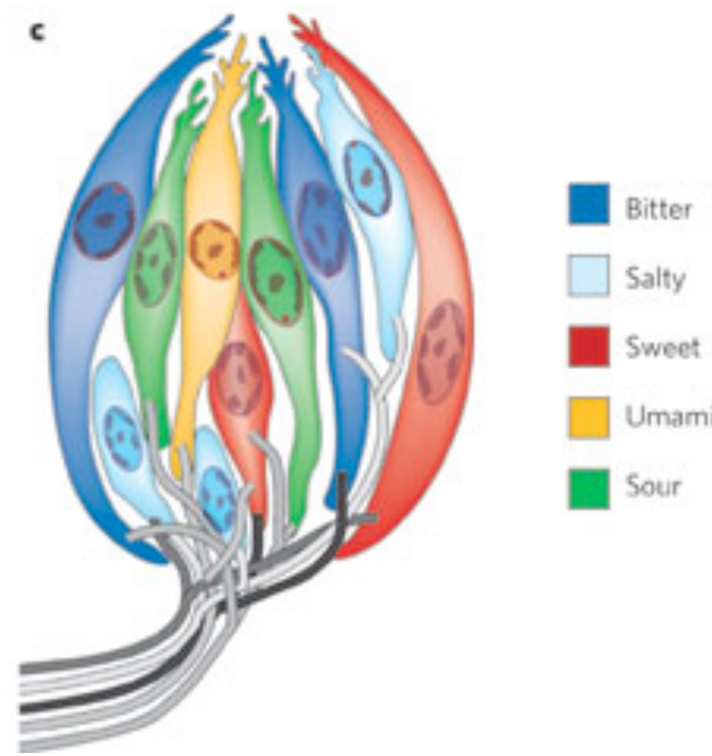
- Very similar to sweet, but slightly different downstream mechanism



# Gustatory System

## Taste Neural Circuitry

- There is no single fiber that conducts one taste quality (i.e. sweet, bitter), but some may respond best to one quality and less well to others
- Branches of nerve fibers innervate several cells within and in between different taste buds



# Miracle Berry Demo


# Miracle Berries

***Synsepalum dulcificum*** is a plant known for its berry that, when eaten, causes sour foods subsequently consumed to taste sweet.

- Plant native to West Africa
- Contains a glycoprotein called **miraculin**, which binds to the tongue's taste buds when the fruit is consumed
- Acts as a sweetness inducer when it comes into contact with acids
- Causes sour and bitter foods to taste sweet

*Crystallographic structure of a dimeric miraculin-like protein.*
*Within each dimer, 2 miraculin glycoproteins are linked by a disulfide bridge.*

# Miracle Berry Demo







*The following items will be used in our miracle berry demo.*

# Miracle Berry Demo

## Instructions

1. Place one miracle berry tablet on your tongue and let it dissolve for **3 minutes**.
   *The miracle berry needs to coat your mouth in order to have an effect, so don't just quickly swallow it down. You should hold it in your mouth and swoosh it around for a little bit on your tongue.*
2. Taste the following items available after **5 to 10 minutes.**
3. Record how the different items taste.

The effect of a miracle berry can last somewhere between **15 minutes to 2 hours**.

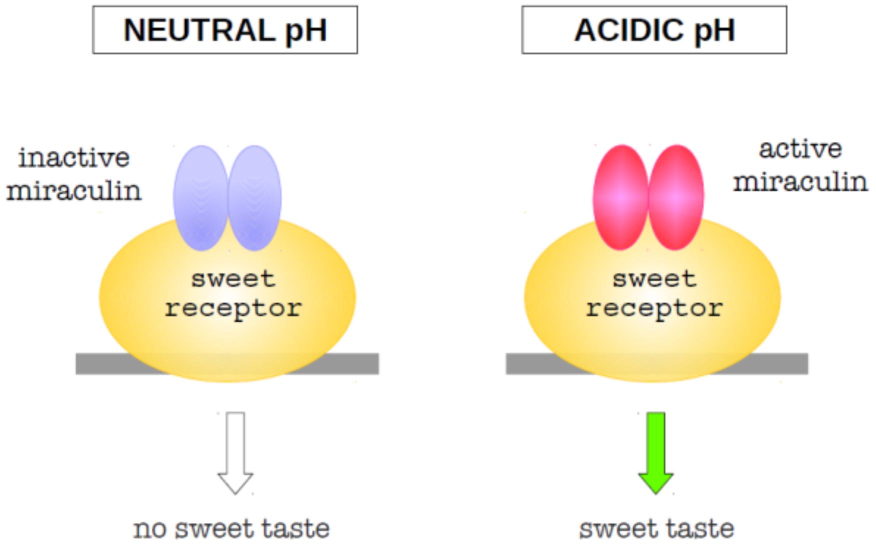
## How do you think Miracle Berries work?

# Miracle Berries

## How do these berries work?

1. Mechanism understood by team of researchers at the University of Tokyo (led by Keiko Abe)
2. Used a system of cultured cells that let them test taste receptors at various levels of acidity and alkalinity
3. Found that miraculin bound strongly to sweet taste buds, but unlike sugar or aspartame, doesn't activate them at a neutral pH
4. When acid is introduced, the protein changes shape and turns on the taste bud.

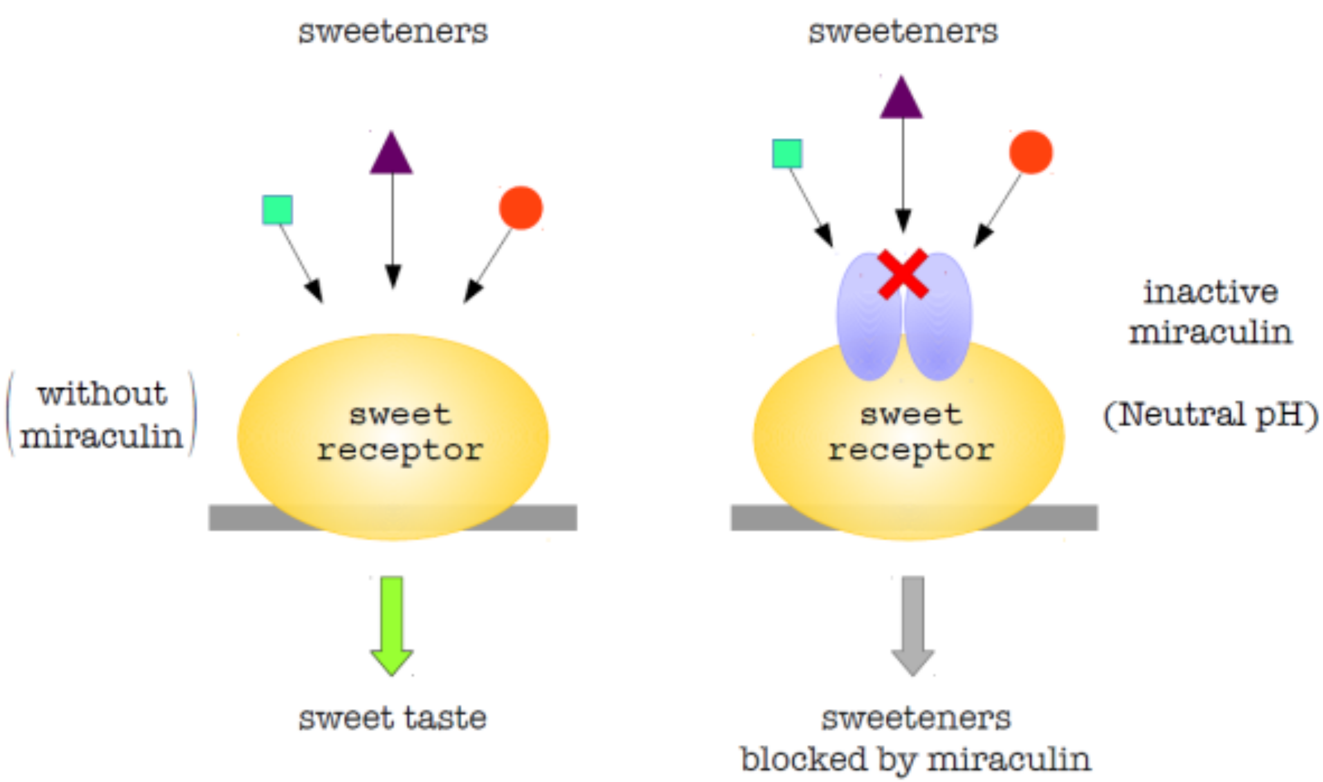
**This causes the ultra-sweet sensation that drowns out the sour taste.**



# Miracle Berries

## How do these berries work?

- When sour food is swallowed, miraculin returns to its old inactive shape and remains bound to the sweet receptor for an hour or so
- Miraculin also disrupts detection of sweet foods. If you have sugar after consuming a miracle berry, you cannot taste it. However, after introducing a little acid, the sugar tastes sweeter than ever.



# Mechanism of Miraculin

- **Miraculin is very unique glycoprotein**

  Most macromolecules do not directly affect and induce taste and smell sensations. Miraculin alters the overall flavor perception by dramatically reducing the sour acuity and augmenting the sweetness acuity.

  *Note:* *High temperatures and high pH substances (above 12) will render miraculin useless as will low pH substances (below 2).*

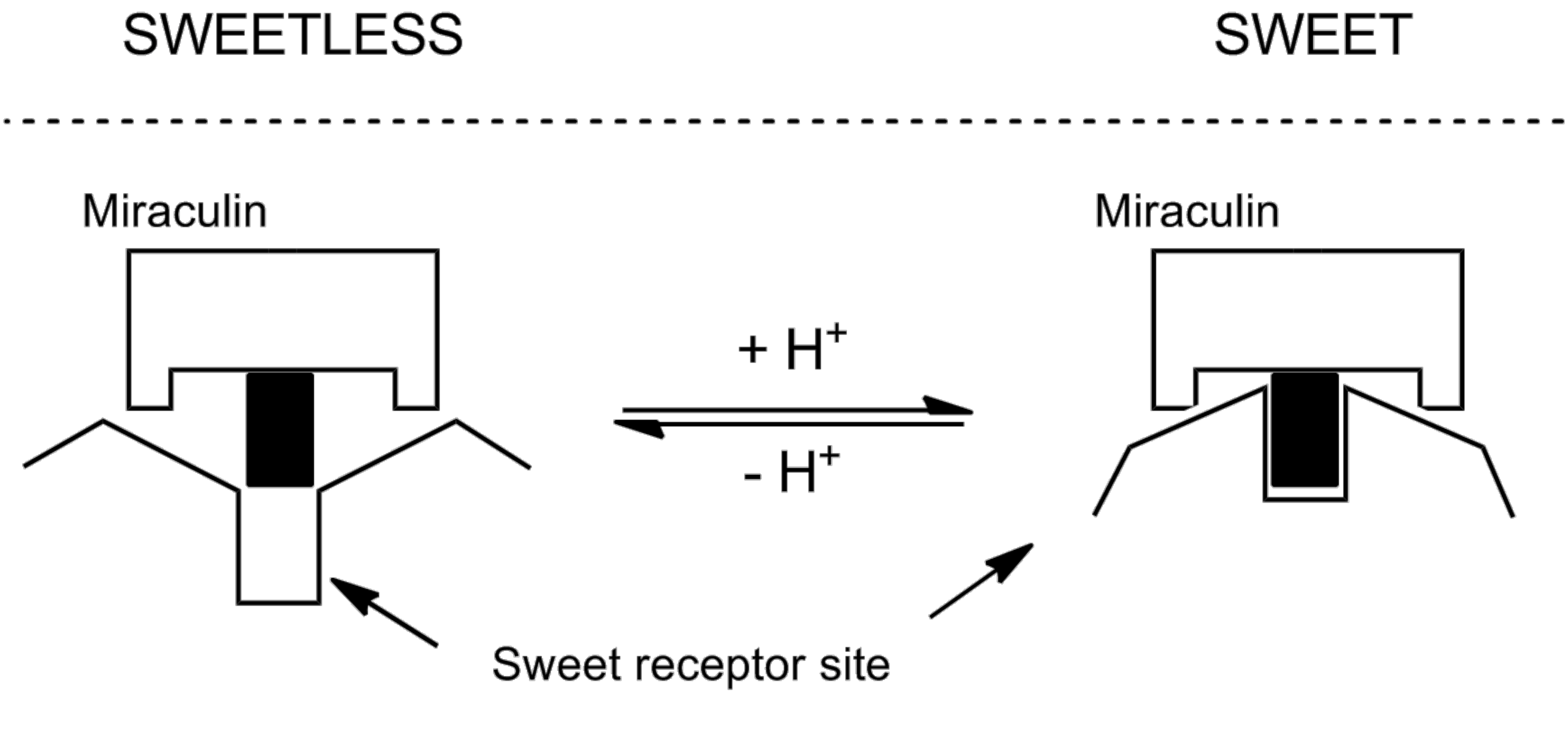
- **Acts as a lock-and-key model with sweet receptors**

  Scientists postulate that miraculin acts as a key and strongly binds to specific "sweet-taste" receptors on the tongue.

- **Adding acid causes initiation**

  When acid is present, miraculin changes its shape and and initiates sweet-taste bud receptors to fire.

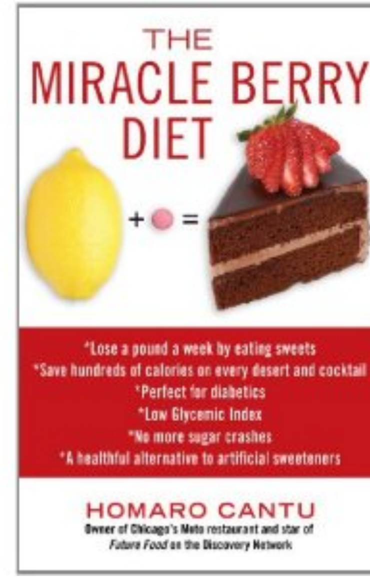
# Mechanism of Miraculin




*Mechanism of taste-modifying activity of miraculin. Reproduced from Kurihara (1992)*

# The Future of Miracle Berries

## 1. Help Patients




<u>Diabetes and Cancer</u>

- Does not activate insulin
- No calories
- Taste enhancer
- Does not induce cravings as sugar does

*Diabetics cannot produce adequate insulin and are on a constant watch to make sure their blood sugar remains in check. This results in sacrificing foods and drinks that contain copious amounts of sugar. Cancer patients often experience loss of taste sensation.*

## 2. Dietary Aid

- Taste indistinguishable from sugar
- 400x sweeter than sucrose
- Used in combination with diet

**Next Time:**

Guest Lecture

by Christos Papadimitriou

*Brain Bank Demo*


*Flight to London, United Kingdom*