

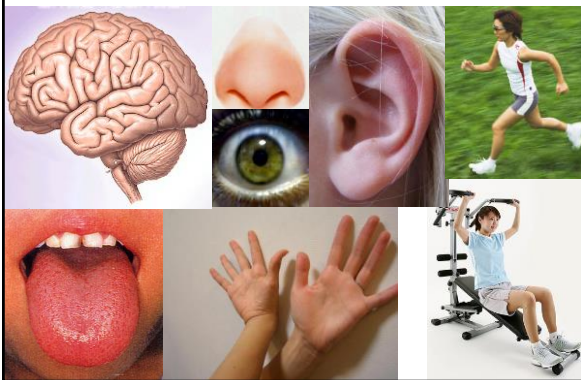
Interactive System  
インタラクティブシステム特論(1)

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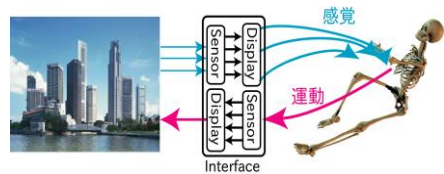
言語 / Language

- 講義は日本語、資料は英語。
- ✓専門用語は併記
- Lecture in Japanese, handouts in English.

Self Introduction: Research field = Human Interface



Necessary Knowledge for the research



- ヒトの特性 / Human perception
- 最新技術(センサ) / Today's sensing technology
- 最新技術(ディスプレイ) / Today's display technology

This Lecture aims to roughly sketch  
"optimal design method based on human perception"

Outline of the lecture



1. 人間計測手法 / Measuring Human
2. 視覚 / Human Vision System
3. 視覚センシング / Visual Sensing
4. 視覚ディスプレイ / Visual Display
5. 聴覚、聴覚インタフェース / Auditory Interface
6. 触覚、触覚インタフェース基礎 / Tactile Interface Basics
7. 触覚、触覚インタフェース応用 / Tactile Interface Applications
8. 力覚、力覚インタフェース / Haptic Interface
9. 移動感覚インタフェース / Locomotion Interface

Schedule

- 4/8 出張のため休講
- 4/15 講義 (lecture)1
- 4/22 講義 (lecture)2
- 4/29 昭和の日
- 5/6 講義 (lecture)3
- 5/13 出張のため休講
- 5/20 講義 (lecture)4
- 5/27 講義 (lecture)5
- 6/3 講義 (lecture)6
- 6/4(土) オープンラボ研究室見学 (任意)
- 6/10 出張のため休講
- 6/17 講義 (lecture)7
- 6/24 講義 (lecture)8
- 7/1 講義 (lecture)9
- 7/8 出張のため休講
- 7/15 プレゼンテーション (presentation)1
- 7/22 プレゼンテーション (presentation)2
- 7/29 プレゼンテーション (presentation)3

### 小テスト/ Mini Test

- 講義の目的の一つが「基礎知識を得ること」なので、各回小テストを行います。
- **メールで回答。メールアドレス: [report@kaji-lab.jp](mailto:report@kaji-lab.jp)**
- メールタイトル: インタラクティブシステム第〇回 (学籍章番号) 山田太郎
- **締め切り: 次回開始まで**
  
- E-mail report based mini tests are done every time.
- **Send email to [report@kaji-lab.jp](mailto:report@kaji-lab.jp)**
- Email title: Interactive System-#N (student ID) Name
- **Deadline: Before the beginning of the next lecture**

### 発表/ Presentation

**Your PowerPoint Presentation is required.**

- 英語の論文を一つ読み、その内容を発表。  
(読む候補はこちらで用意します)

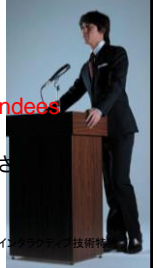
**Read a paper and do presentation.  
(candidate papers will be announced)**

– 今のところ発表8分、質疑4分.

- 発表は全員で評価

**The presentation is evaluated by all attendees**

- 1. 発表内容に対する理解度
- 2. 発表用資料(パワーポイント)の分かりやすさ
- 3. 発表の分かりやすさ
- 4. 質問に対する受け答え
- 5. 総合的な印象



### 評価/ Evaluation

- 点数 = 出席(40%) + 小テスト(5% × 8) + 発表(20%)
- **ただし発表をすることが評価の前提条件**
- 電通大以外の場合(スーパー連携大学院) = Attendance (60%) + Mini Test (5% × 8)
  
- Evaluation = Attendance (40%) + Mini Test (5% × 8) + Presentation (20%)
- Presentation is required

### Handouts on the web

<http://kaji-lab.jp/ja/index.php?people/kaji/interactive>

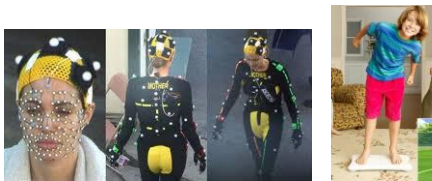
–現在は2015年版がおかれています。徐々に変えていきます。  
–Temporary, 2015 Japanese version. Will be replaced progressively.

**–こちらのpdfには動画のリンク先(Youtube等)が埋め込まれているので、紙資料よりも便利。次回から紙資料は配布せず、講義の1時間前までにアップロードします。必要なら事前にダウンロードしてください**

**–From next time, lecture handouts will be online 1 hour before the lecture. Print it if necessary.**

### Today's Topic:

## 人間計測手法 / Measuring Human



#### ヒトの計測:

- インタラクティブシステムの**構成要素**
- インタラクティブシステムを**評価するため**にも必須

#### Measurement of human action/reaction

- To be used **as parts of** the interactive system
- To **evaluate** the system

## 人間計測手法 / Measuring Human

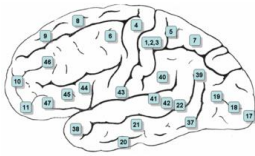


意志から行動までの「どの経路を測るか」で5つの段階  
Five layers, *from our initial will to our perception.*

- 脳活動計測 / Measure **brain activity**.
- 神経・筋活動計測 / Measure **nerve activity**.
- 自律神経系計測 / Measure **autonomic nerve** related phenomenon.
- 運動計測 / Measure **motion**.
- 心理物理実験 / Ask the user (**psychophysics**)

## History of Brain Function Observation(1)

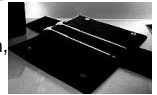
- Theory of localization of brain function :
  - 1909 : **ブロードマン** Brodmann made "map" of the brain by visual observation. (microscope)
  - WWI: Better guns = many patients with "partial" brain damage



Brodmann's map:  
52 regions of the cortex defined based on organization of cells.

## History of Brain Function Observation(2)

- 1933: **ペンフィールド** Penfield  
Before Brain surgery for epilepsy, he stimulated brain directly by electrical needle. while the patients were awake.  
Result: Many functional region were found, including memory, sensory, and action.
- 1940: **ロボトミー** Lobotomy  
Cut frontal lobe of the brain for mental disease, especially for violent patients.  
Result: Became calm, but also became like "robot" ⇒ Frontal lobe seems to be related to "emotion"
- 1960: X-ray CT gave clear view of the brain, without surgery.

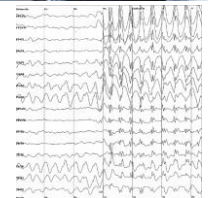


## 脳機能計測 / Measurement of Brain Function

- Not the measurement of brain, but brain function. Must be done during some work. (see, touch, think)
- State-of-the-art measurement technologies are used.
  - Measure "Electrical Activity"
    - 脳波 / EEG (brain wave), 1929~
    - 脳磁 / MEG, 1972~
  - Measure "Blood Flow"
    - fMRI (functional MRI), 1973~
    - PET, 1965~
    - NIRS, 1994~
  - Active method
    - Use magnetic stimulator

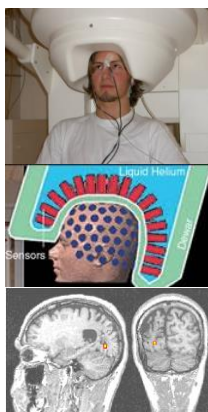
## EEG (Brain Wave)

- EEG: Electroencephalogram
- 21~60 electrodes on the skull skin.
- Good points
  - Cheap!
  - Very fast (ms)
- Bad points
  - Low spatial resolution.
  - Skin-electrode conductance is unstable.
  - Can measure "surface", but cannot measure "deep region"
- Still used in many interactive systems



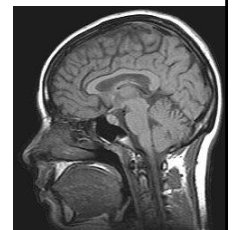
## MEG

- MEG: Magnetoencephalography
- Similar to EEG, but measure "magnetic field" induced by electrical current.
- **Very, very tiny magnetic field** (about  $1/10^8$  of the earth's magnetic field)
- Superconducting technology is used. (SQUID: Superconducting Quantum Interference Device)
- Good points
  - Very Fast (similar to EEG)
  - Can measure deep region. (magnetic field penetrates everything) .
- Bad points
  - Surface sensors = 2D
  - Current sources = 3D mathematically very difficult to solve (almost impossible)



## MRI (核磁気共鳴画像法)

- MRI: Magnetic Resonance Imaging
  - Very strong magnetic field make protons to "emit" electromagnetic waves.
  - By measuring this waves, can obtain 3D structures.
- Good points (compared to X-ray CT)
  - No X-ray (=good for body)
  - Bone is not an obstacle
  - 3D data are obtained (X-ray CT: 2D)
- Bad points
  - Very strong magnet (3T-): metal cannot be carried on.
  - Takes a few seconds for a single shot (now improving).
- Current standard for "brain imaging"

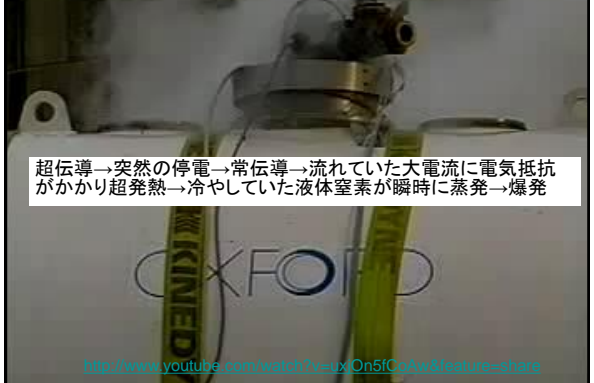


## 100fps MRI



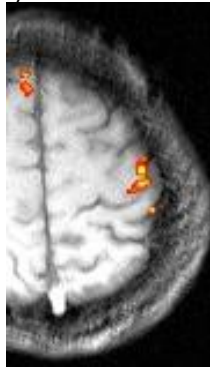
- <http://japanese.engadget.com/2015/04/23/100fps-mri/>
- イリノイ大学アーバナ・シャンペーン校のベックマン先端科学技術研究所が、秒間100コマの撮影が可能なMRI技術を開発しました。
- ベックマン研究所が開発した技術を大雑把に説明すれば、単純にフレームレートを上げると発生してしまうS/N比の低下を回避するため、フレーム間を補完する特殊な取得方法を開発、利用しているとのこと。これにより撮像時間は従来のおよそ10倍、約100fpsにまで高められています。
- 論文は Magnetic Resonance in Medicine誌 "High-resolution dynamic speech imaging with joint low-rank and sparsity constraints" (Maojing Fu, Bo Zhao, Christopher Carignan, Ryan K. Shosted, Jamie L. Perry, David P. Kuehn, Zhi-Pei Liang, and Bradley P. Sutton)

## Exploding MRI



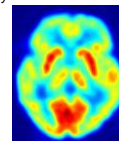
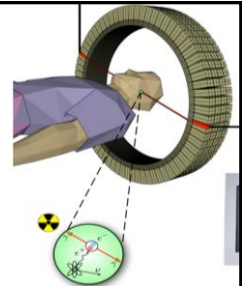
## fMRI = functional MRI (機能的MRI)

- We must measure brain "activity", not shape.
  - By using MRI, measure "blood flow", by measuring two hemoglobins' ratio.
  - Hemoglobin: container of oxygen.
    - Red = many oxygen.
    - Blue = few oxygen.
- Good point
  - Location is very accurately determined.
- Bad point
  - Requires a few minutes for single shot.
- Current standard for brain functional imaging.



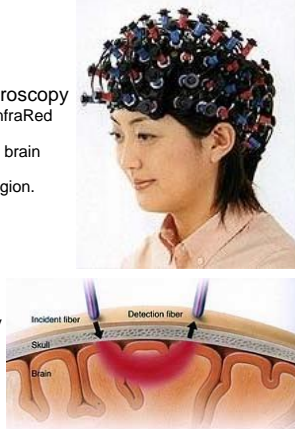
## PET (ポジトロン断層法)

- PET = Positron Emission Tomography
  - Inject Radioactive ingredient as a "tracer" (O15)
  - The "tracer" collapses, and generate two "γ waves" to the opposite direction.
  - The detector detects the phenomenon.
  - Position is determined by timing measurement.
  - Blood flow can be measured.
- Good point
  - A little faster than fMRI (a few second)
- Bad points
  - radioactive ingredient is necessary.
  - Lower resolution than MRI



## NIRS (近赤外分光法)

- NIRS = Near InfraRed Spectroscopy
  - Skull bone is transparent to InfraRed light.
  - Put InfraRed light, and obtain brain surface image.
  - Hemoglobin: container of oxygen.
    - Red = many oxygen.
    - Blue = few oxygen.
- Good points
  - No invasive. Easy to use.
- Bad points
  - Low spatial resolution
  - A few seconds are necessary



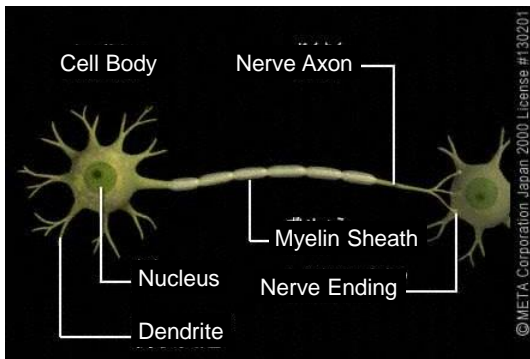
## Summary of Brain Functional Imaging

手法 Method	観察対象 Observe	空間解像度 Spatial Resolution	時間解像度 Temporal Resolution
EEG	Electric	Low	High
MEG	Electric	Low	High
fMRI	Blood	High	Low
PET	Blood	Mid	Mid
NIRS	Blood	Mid	Mid

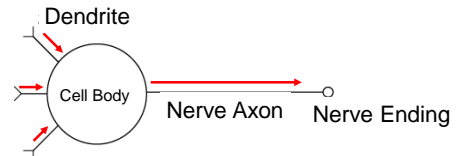




## Nerve: Basics

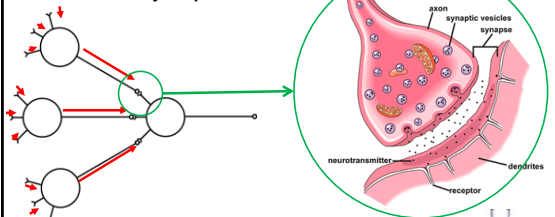


## Nerve structure



- 樹状突起 / Dendrite: Input Connector
- 細胞体 / Cell Body: Calculator (Summation)
- 軸索 / Axon: Output Cable
- 神経終末 / Nerve Ending: Output Connector

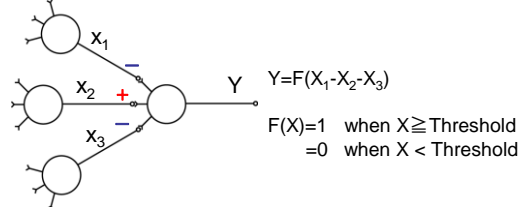
## シナプス / Synapse



- Nerve Ending – Dendrite Connection
- 20nm "Synaptic cleft"
  - First Discovery: Electron Microscope
- 1st nerve: Electrical Pulse  $\Rightarrow$  Chemical Output
  - Capsules break, and neurotransmitter showers.
- 2nd nerve:  $\Rightarrow$  Chemical Input  $\Rightarrow$  Electrical Current
- "One way" connection
- 0.1-0.2ms necessary

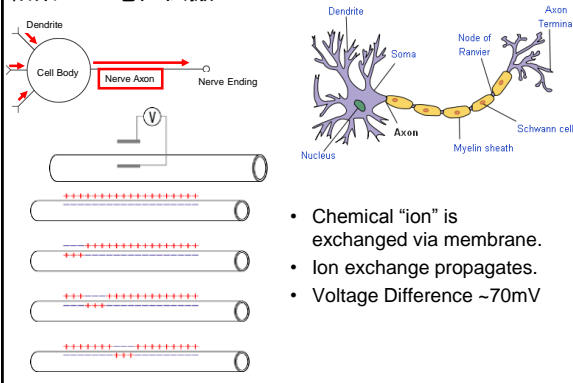


## 興奮性シナプス・抑制性シナプス Excitatory Synapse, Inhibitory Synapse



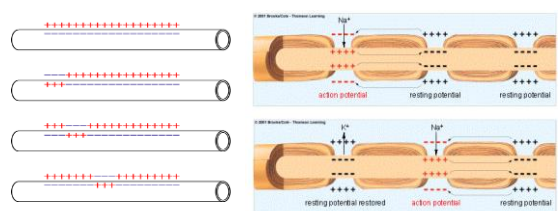
- Cell Body: Take Summation  $\Sigma$
- **Excitatory Synapse: Plus(+) input**
- **Inhibitory Synapse: Minus(-) input**
- Synaptic weight change = Learning and Memory

## 軸索上の電位伝搬 / Axonal Transmission



- Chemical "ion" is exchanged via membrane.
- Ion exchange propagates.
- Voltage Difference  $\sim$ 70mV

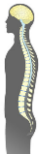
## 軸索のタイプ / Axon types



- Axon length: Reaches to 1m.
- ミエリン鞘 / Myelin Sheath: Insulator
- Electrical Current is limited to very small "gap" (ランビエ絞輪 / Ranvier Node)  $\Rightarrow$  Very Fast "Skip"
- 有髄神経: Myelinated axon = very fast
- 無髄神経: Unmyelinated axon = very slow

## 信号伝搬速度 / Conduction Velocity

	name	diameter(μm)	velocity(m/s)	role
有髄神経 Myelinated	Aα	15	100	Many muscle nerves
	Aβ	8	50	Many sensory nerves
	Aγ	5	20	Some muscle and sensory nerves
	Aδ	3	15	Fast pain
無髄神経 Unmyelinated	C	0.5	1	Slow pain, heat, cold sensation, etc



- Rule: Thicker = Faster
- Myelinated Axon: Invention of vertebrate animals (animals with back-bone).
- Other animal's strategy: Thicker the better.
  - ex) Squid's gigantic nerve (diameter: 0.5mm)



## Conduction velocity and diabetic (糖尿病)

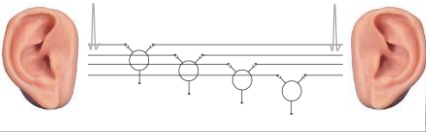
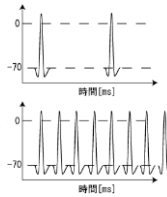
**Normal Myelin Sheath**

**Damaged Myelin Sheath**

- Diabetic: Quite common disease by taking too much sugar.
- It damages Myelin Sheath so that nerve conduction is inhibited.
- Finally, one cannot sense anything (blind, etc)
- Inspection: measure conduction velocity

## Information Coding by the Nerve

- Repetition Ratio
    - Strong Stimulus ⇒ High Frequency
    - Single pulse means nothing.
  - Timing
    - One nerve is activated when two inputs come simultaneously (at the same time).
- (ex) Owl's Sound-Source Detection Mechanism



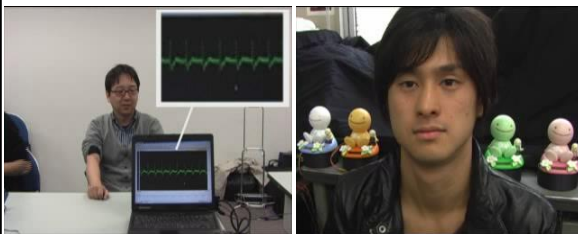
## 筋電計測

### Measurement of muscle fiber activity

- Muscle Nerve ⇒ Muscle Fiber Activity
- Relatively easy with differential amplifier circuit (差動増幅回路).
- Problem: Conductive Gel is required.

## (ex) 笑いの増幅

### Augmentation of Laugh



- Take initial laugh timing by measuring muscle activity.
- Enhance the laugh by using "empathy effect"

## 最先端の筋電計測

### State-of-the-art Muscle Measurement



Figure 1. Illustration of the relevant forearm muscles. The distal view shows the extensors, the palmar view shows the flexors. The right hand picture shows a cross section of the forearm in the middle between the distal and the proximal end. The red line around it indicates the approximate position of the electrode array. The muscles are 1: M. extensor digitorum communis, 2: M. extensor digiti minimi, 3: M. extensor pollicis longus, 4: M. extensor pollicis longus, 5: M. extensor indicis, 6: M. flexor digitorum profundus, 7: M. flexor pollicis longus, 8: M. flexor digitorum superficialis (pictures from Wikimedia Commons)



Figure 2. Picture of the electrode array used. The inter-electrode distance is 10 mm. The electrodes are arranged in a 8x24 grid. Electrode numbering starts at the lower left corner and works columnwise.

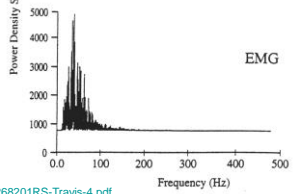
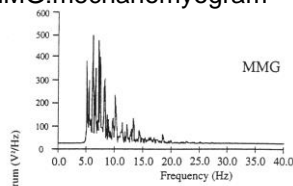
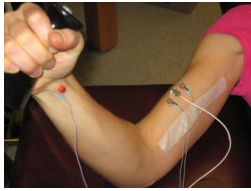
8x24の電極群を前腕に巻きつけジェスチャ学習



Figure 3. Picture of the actual setup used: (1) electrode array, (2) pre-amplifier, (3) reference electrode, (4) EMG circuit, (5) data glove (not used), (6) real-time signal visualization, (7) patching software, (8) amplifier, (9) recording computer

Christoph Amma et al., Advancing Muscle-Computer Interfaces with High-Density Electromyography, CHI2015

(発展トピック)筋音計測MMG:mechanomyogram



- 筋繊維の「きしみ」で音が出る現象。
- 加速度計やマイクを体表に貼付するだけで非侵襲測定
- 皮膚表面状態（汗等）に影響されない
- EMGに比べ低周波
- 原理は完全には未解明

[http://www.trnres.com/ebook/uploads/travis/T\\_1279268201RS-Travis-4.pdf](http://www.trnres.com/ebook/uploads/travis/T_1279268201RS-Travis-4.pdf)

人間計測手法／Measuring Human



意志から行動までの「どの経路を測るか」で5つの段階  
Five layers, from our initial will to our perception.

- 脳活動計測／Measure brain activity.
- 神経・筋活動計測／Measure nerve activity.
- 自律神経系計測／Measure autonomic nerve related phenomenon.
- 運動計測／Measure motion.
- 心理物理実験／Ask the user (psychophysics)

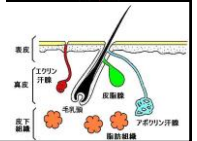
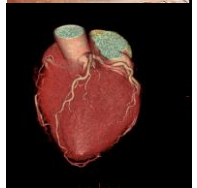
自律神経／Autonomic Nervous System

Nervous system that acts as a body control system.  
Composed of Sympathetic nervous system(SNS:交感神経)  
and Parasympathetic nervous system(PSNS:副交感神経).



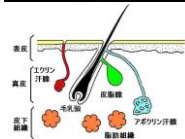
Sympathetic nervous system (SNS:交感神経)

- Nervous systems for “Fight and Flight” (闘争と逃走)
- Eye Pupils (瞳孔) →Open
- Heart(心臓) →Blood Pressure & Beat ↑
- Skin(皮膚)
  - Sweat Grand(汗腺)→Sweat(発汗)
  - Hair Elector Muscle (立毛筋)→Contract(収縮)
- Blood Vessel(血管) →Expand 拡張(一部収縮)



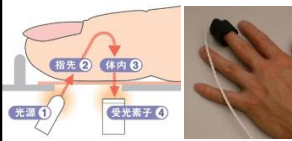
Parasympathetic nervous system (PSNS:副交感神経)

- Nervous systems for “calming” (沈静)
- Eye Pupils (瞳孔) →Close
- Heart(心臓) →Blood Pressure & Beat ↓
- Blood Vessel(血管) →Contract 収縮(一部拡張)



情動を測定／Measure Emotional State

- Heartbeat & Blood Pressure (心拍数、血压)
- Pulse Wave (脈波)
- GSR(galvanic skin response, 皮膚電気反応)
- Eye movement (眼球運動)







BPニュースセレクト

「恋人との相性チェックに」、ロームが指輪型脈波センサーを開発  
2010/10/7 7:00

ロームは、大きさが指輪サイズと小さい脈波センサを「CEATEC JAPAN 2010」(2010年10月5~9日、幕張メッセ)に出展した。ヘルスケア機器のほか、ゲーム機や音響機器などアミューズメント分野に向けて開発中のものである。展示ブースでは、ストレス度の測定や恋人との相性チェックに応用したデモンストレーションを披露している。

この脈波センサは、LED光を指に当て、反射光または透過光をフォトダイオードで受け取ってヘモグロビン流量の変化を検出するもの。LED光には黄緑色光などが使えるという。取得したデータを無線送信するためのモジュールを搭載する。村田製作所が出展中の指輪型「ルスメータ」と同様の構成だ。

測定の様子

### 人間計測手法 / Measuring Human







意志から行動までの「どの経路を測るか」で5つの段階  
Five layers, from our initial will to our perception.

- 脳活動計測 / Measure brain activity.
- 神経・筋活動計測 / Measure nerve activity.
- 自律神経系計測 / Measure autonomic nerve related phenomenon.
- 運動計測 / Measure motion.
- 心理物理実験 / Ask the user (psychophysics)

### 行動計測 / Measuring Motion

- Motion Capture System
  - 光学式 / Optical
  - 機械式 / Mechanical
  - 磁気式 / Magnetic
  - ビデオ式 / Image Processing\*
- 一長一短 / Pros and Cons
  - 遮蔽問題 / Occlusion
  - ワークスペース / Workspace
  - 金属の影響 / Effect of Metal

\*KINECT等の詳細は後の回で

### Simpler

- Gaming controllers can be used as a measuring device.
  - 重心動揺計測 ⇒ Wii Balance Board
  - 運動計測 ⇒ Wii Remote
  - 全身運動など: KINECT, Leap Motionなどの台頭
- 簡単なものは自作可能
  - 加速度センサ、ジャイロセンサ






### 人間計測手法 / Measuring Human






意志から行動までの「どの経路を測るか」で5つの段階  
Five layers, from our initial will to our perception.

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### Psychophysics

- Measure relationship between subjective sensation and physical stimulation.
  - ≡ Measure Human's sensing "ability".
- Important value: "Discrimination threshold"
  - Limitation of "difference of two stimuli"  $\Delta P$ , which is perceptible  
ex)
    - $P=30g \Rightarrow \Delta P=3g$
    - $P=3kg \Rightarrow \Delta P=300g$
- Weber-Fechner's law (1834)
  - $\Delta P / P = \text{Constant}$
  - Can be applied to most sensation.

## Weber-Fechner's Law



- $P=P(S)$ 
  - P: subjective value of sensation
  - S: physical value of stimulation
  - $\Delta P$  = subjective "scale" of sensation
- $\Delta P/P = \text{Constant}$ 
  - Integral of both sides gives



$$S \propto \log P$$

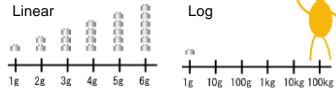
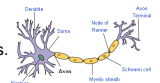
- **Conclusion: Our internal "scale" is logarithmic**

- ex:
  - Audio's rotary volume



## Why Log? = Why not Linear?

Our nerve quantizes the phenomenon by impulses. When we have only 6 scales...



By using Log scale, we can perceive more phenomena.

- (ex) CCD cam: 20dB~30dB
- Huma Eye: 80dB(Can see stars and sun)



## Method of Psychophysical experiment

### Purposes

- Measure "Discrimination Threshold" (DT), which gives  $\Delta P$
- Measure "Point of Subjective Equality" (PSE).
- Perceive two different stimuli as "same".



Discrimination Threshold (DT)  
= What is the necessary difference for discrimination



Point of Subjective Equality (PSE)  
= What is the value of left weight, which can be perceived as "same" as the right weight.

### Major Methods:

**Method of Adjustment, Method of Limit, Method of Constant**

● **調整法 / Method of Adjustment**  
被験者が調整する

Easy, Rough

● **極限法 / Method of Limit**  
実験者が調整する

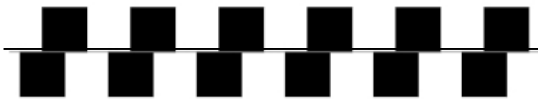


● **恒常法 / Method of Constant**  
調整せず回答の確率分布を見る

Time Consuming, Precise

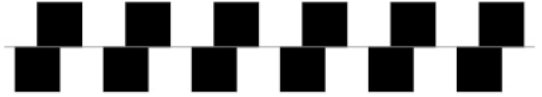
## 調整法 / Method of Adjustment

カフェウォール図形: 確かに水平



## 調整法 / Method of Adjustment

標準刺激 / Standard Stimulus



比較刺激 / Comparison Stimulus



標準刺激の方が傾いて見よ錐的等価刺激を使い回転



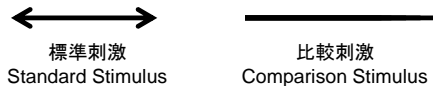
### 極限法 / Method of Limit

ミュラー・リヤー錯視  
確かに同じ長さです



### 極限法 / Method of Limit

#### 1. 下降系列 / Descending Series



同じく比較刺激の方が長い → 回答「小」



このときの比較刺激の長さ = 上閾値 / Upper Threshold

### 極限法 / Method of Limit

#### 2. 上昇系列 / Ascending Series



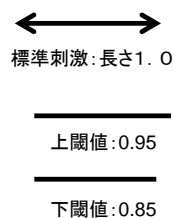
同じく比較刺激の方が短い → 回答「大」



このときの比較刺激の長さ = 下閾値 / Lower Threshold

### 極限法 / Method of Limit

#### 閾値の計算 Threshold Calculation



この結果から、  
 ・主観的等価点 (Point of Subjective Equality) は  $(0.85 + 0.95) / 2 = 0.90$   
 ・弁別域 (Discrimination Threshold) は  $(0.95 - 0.85) / 2 = 0.05$

つまり、この「矢印の錯視」によって、  
 ・長さが0.9に縮んで見えること、  
 ・長さの弁別能力が0.05程度であることが分かった。

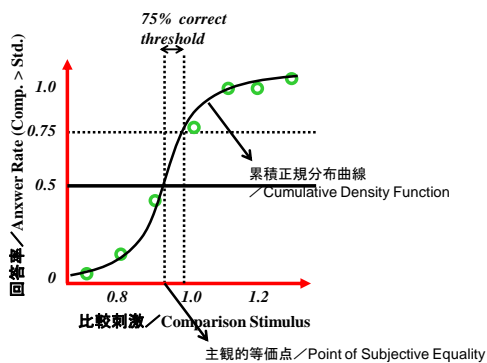
### 恒常法 / Method of Constant



- 比較刺激を複数用意する (例では7個)
- 一個の比較刺激あたりの実験回数を例えば20回とする
- 合計  $7 \times 20 = 140$  回、「ランダムに」比較し、強制二択させる

比較刺激	「比較刺激の方が長い」	「比較刺激の方が短い」
0.7	1	19
0.8	3	17
0.9	9	11
1.0	15	5
1.1	17	3
1.2	19	1
1.3	20	0

### 恒常法 / Method of Constant



## Today's Summary

Measurement of Human perception is necessary for interactive system design.

- 脳活動計測 / Measure **brain activity**.
- 神経・筋活動計測 / Measure **nerve activity**.
- 自律神経系計測 / Measure **autonomic nerve** related phenomenon.
- 運動計測 / Measure **motion**.
- 心理物理実験 / Ask the user (**psychophysics**)

They can be used both as a **evaluation tool**, and **part of an interactive system**



## 小テスト / Mini Test 次回開始までにメール

以下の全てに100字以内程度で解答せよ / Answer all questions within 50 words

1. EEGについて説明せよ Explain EEG
2. MEGについて説明せよ Explain MEG
3. MRIについて説明せよ Explain MRI
4. PETについて説明せよ Explain PET
5. NIRSについて説明せよ Explain NIRS
6. 有髄神経と無髄神経の違いについて述べよ Describe difference between myelinated and unmyelinated nerves.
7. 交感神経の活動で生じる現象を3つ挙げよ Quote three phenomena related to SNS (Sympathetic nervous system) activity.
8. ウェバー・フェヒナーの法則について説明せよ Explain Weber-Fechner's law
9. 調整法について説明せよ Explain the method of adjustment.
10. 極限法について説明せよ Explain the method of limit.
11. 恒常法について説明せよ Explain the method of constant.

## Handouts on the web(再掲)

<http://kaji-lab.jp/ja/index.php?people/kaji/interactive>

-現在は2015年版がおかれています。徐々に変えていきます。  
-梶本研→メンバー→梶本→講義→インタラクティブシステム特論  
-Temporary, 2015 Japanese version. Will be replaced progressively.

-こちらのpdfには**動画のリンク先(Youtube等)が埋め込まれているので、紙資料よりも便利。紙資料は配布せず、講義の1時間前までにアップロードします。必要なら事前にダウンロードしてください**

-**From next time, lecture handouts will be online 1 hour before the lecture. Print it if necessary.**