Brain Computer Interfaces

restoring touch and proprioception

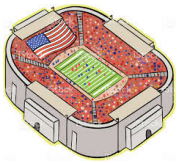
david bjånes, m.s.
phd candidate
electrical engineering

outline

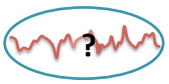
- **why** study neuroscience?

- **how** did I get here?

- **what** is a brain computer interface (BCI)?
  - **how** do talk to (and listen) to the brain?



- **my research**…



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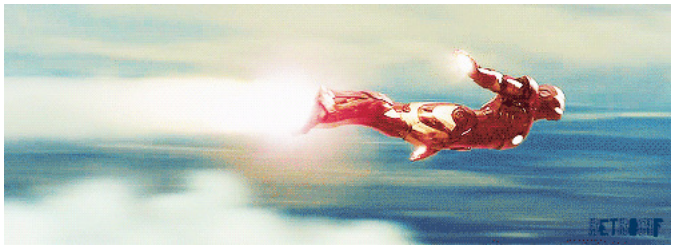
why study neuroscience?

why study neuroscience?

- **ironman**



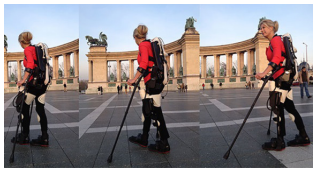
why study neuroscience?

- ironman
- **impossible problems**

why study neuroscience?

- ironman
- impossible problems
- **help people**

Stroke



Paralysis

Amputation

why study neuroscience?

6.6 million patients have suffered a stroke (610,000 1st time/year) [3]

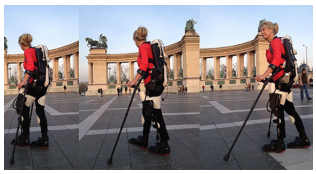
Post stroke: 9% increase in disability, 11% risk of institutionalism

282,000 patients live with a spinal cord injury (17,000/year) [1]

1.9 million amputees (185,000/year) [2]

Prosthetics: 27-59% use of upper limb, 49-95% of lower limb

Stroke



Paralysis

Amputation

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[1] National Spinal Cord Injury Statistical Center, Facts and Figures at a Glance. Birmingham, AL: University of Alabama at Birmingham, 2016.
[2] Heinemann, A. W., Bode, R. K., & O'reilly, C. (2003). Development and measurement properties of the Orthotics and Prosthetics Users' Survey (OPUS): a comprehensive set of clinical outcome instruments. *Prosthetics and Orthotics International*, *27*(3), 191-206.
[3] Circulation: Heart Disease and Stroke Statistics—2016 Update. http://circ.ahajournals.org/content/133/4/e38.full.pdf

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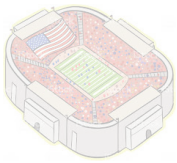

- **my research**…

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first lego league

9

active prosthetics

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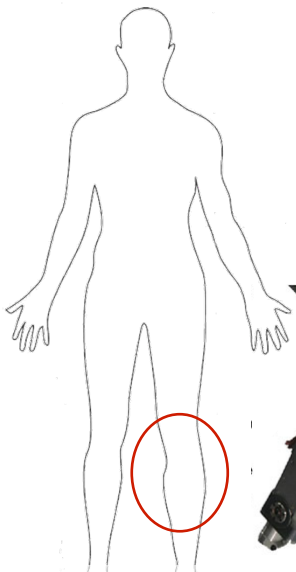


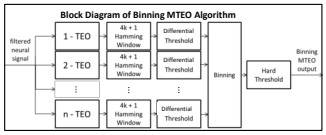
MIT Media Lab (2009)
Dr. Hugh Herr

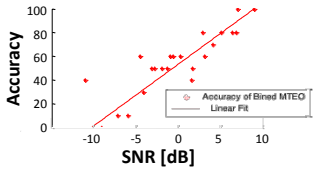
- designed two motor controller PCBs for an active knee prosthetic device [5]

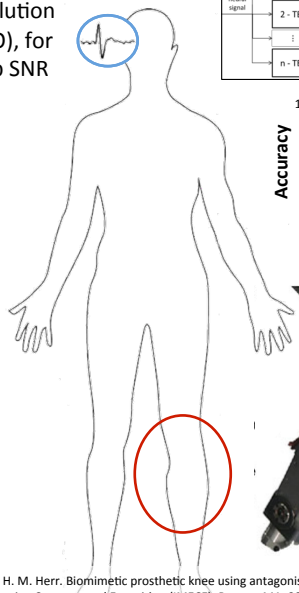
- helped test a parallel leaf spring exoskeleton to increase metabolic efficiency of walking [6]

[5] E.C. Martinez-Villalpando, J. Weber, G. Elliott, and H. M. Herr. Biomimetic prosthetic knee using antagonistic muscle-like activation, ASME International Mechanical Engineering Congress and Exposition (IMECE), Boston, MA, 2008.
[6] G. Elliott, A. Marecki and H. Herr. Design of a Clutch–Spring Knee Exoskeleton for Running, Journal of Medical Devices, vol 8, no. 3, 031002-031002-11, July. 2014.

Cornell University (2011) – Dr. Alyosha Molnar developed mTEO, multi-resolution Teager Energy Operator (TEO), for neural spike detection in 0db SNR conditions







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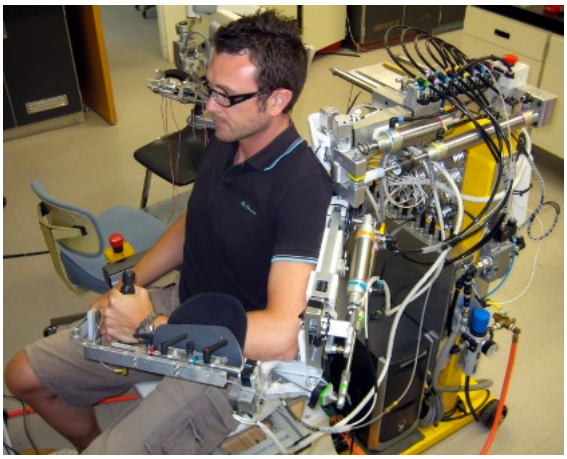
rehabilitation



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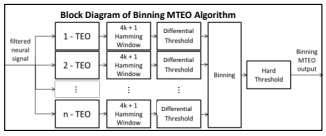
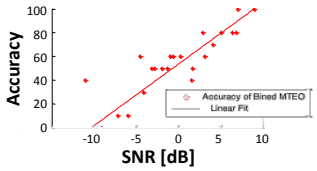
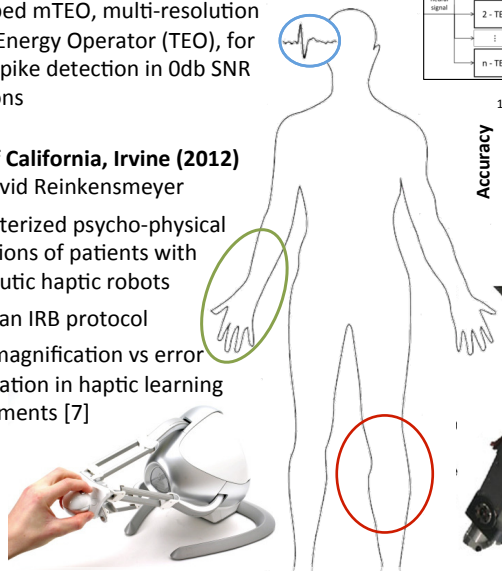




Univ. of California, Irvine (2012)
Dr. David Reinkensmeyer

- characterized psycho-physical interactions of patients with therapeutic haptic robots
- wrote an IRB protocol
- error magnification vs error minimization in haptic learning environments [7]



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[7] D.A Bjanes, D Reinkensmeyer, in progress.

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    - active prosthetics (m.i.t. media labs)
    - spike detection (cornell university)
    - therapeutic haptic robotics (univ. of california irvine)
- **graduate school**
  - m.s. in electrical and computer engineering
    - spike sorting (univ. of pittsburgh)
  - ph.d. in electrical engineering
    - sensory feedback stimulation (uw)

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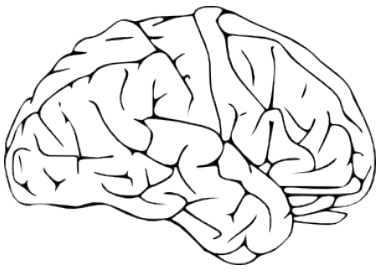
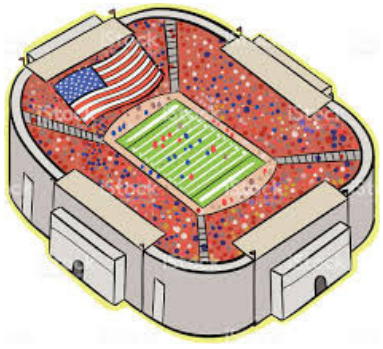
brain = stadium





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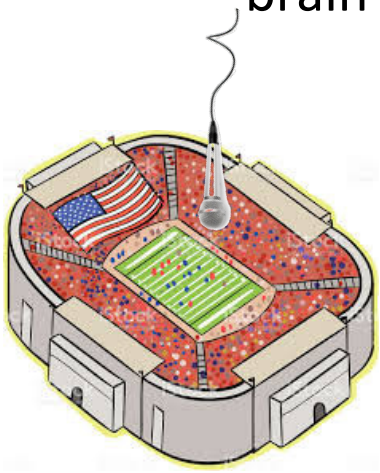
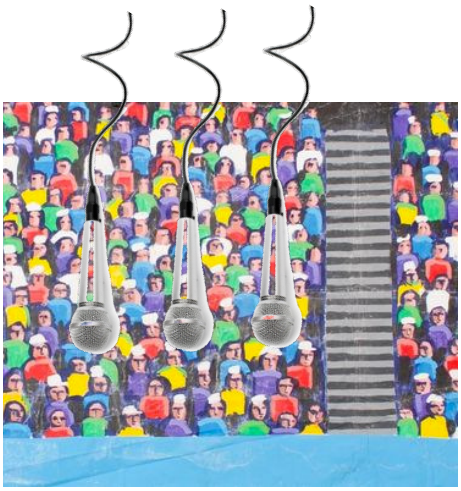
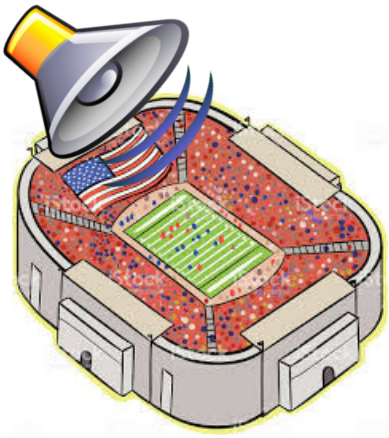
brain = stadium

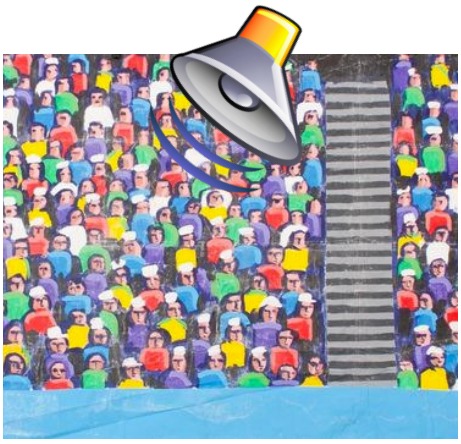




17

brain = stadium





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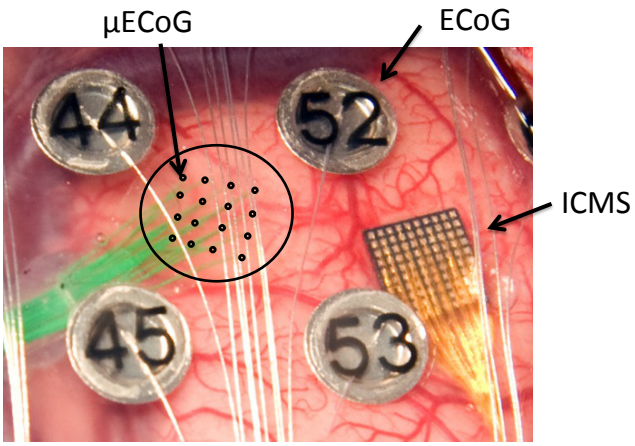
Aim 3: Electrode Interfaces



Kellis SS, House PA, Thomson KE, Brown R, Greger B. Human neocortical electrical activity recorded on nonpenetrating microwire arrays: applicability for neuroprostheses. *Neurosurgical focus*. 2009;27(1):E9. doi:10.3171/2009.4.FOCUS0974.

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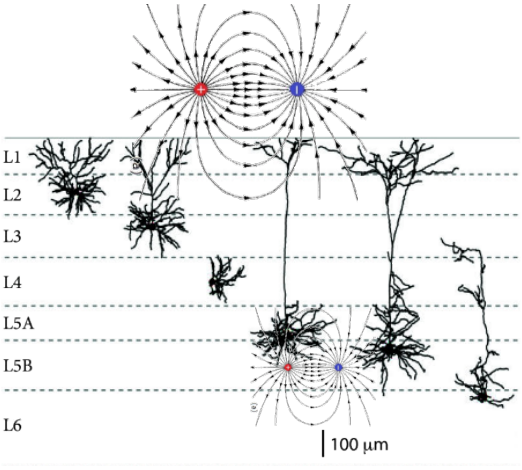
Activation pathway for µECoG and ICMS

- Larger currents are needed to penetrate cortical layers
- Possible activation of descending tracts
- Diffusion likely to occur, affecting temporal and spatial specificity



S. Lefort, C. Tomm, J.C.F. Sarria and C.C.H. Petersen (2009) *The excitatory neuronal network of the c2 barrel column in mouse primary somatosensory cortex. neuron 61: 301-316.. Neuron* **61**, pp. 301–316.

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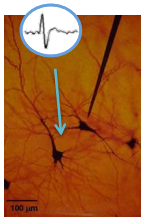
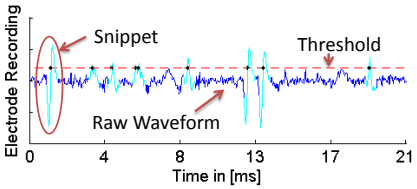
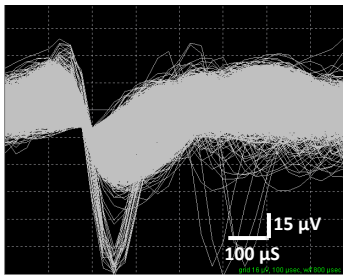
spike sorting

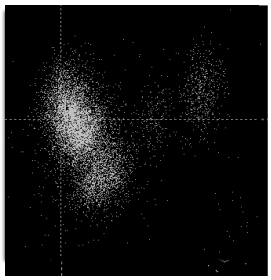




Snippets



Snippets - PCA



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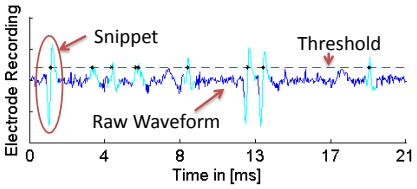

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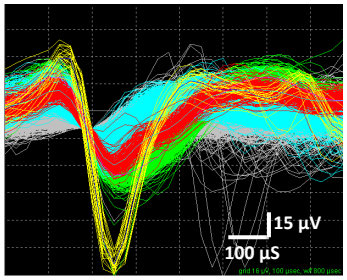

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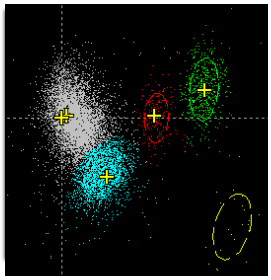

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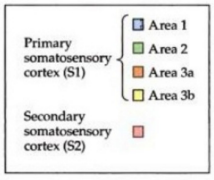
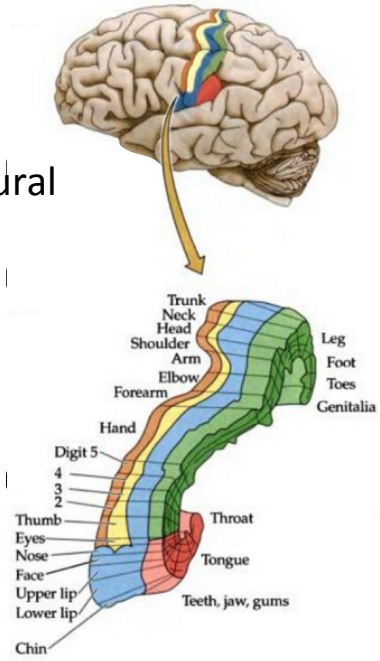
Somatosensory Cortex

record /stimulation neural activity from:

- **Area 1**
- Area 2
- Area 3b





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[2] Ali, Farzana 2015. http://www.slideshare.net/FarzanaAli6/lecture-12-somatosensory-system-and-nociception, Slide: 21

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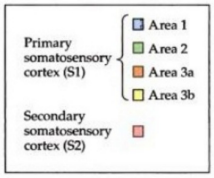

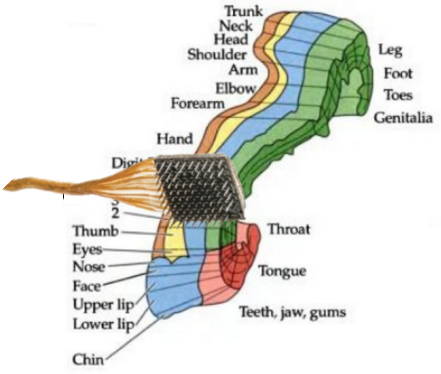

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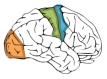
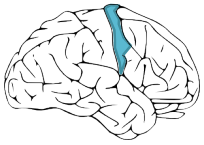


M1



Motor Output

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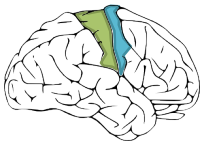
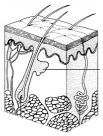
S1 M1



Motor Output

Delay:
20 - 50 ms



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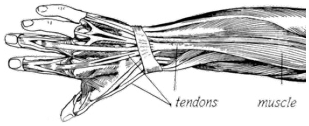

Tactile and Proprioceptive Feedback

[1] Efron, Robert. "The minimum duration of a perception." Neuropsychologia8.1 (1970): 57-63.

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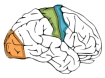


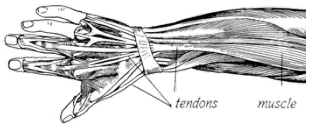
S1 M1

V1

Motor Output

Delay:
20 - 50 ms

+



Delay: 120 - 240 ms

Visual Feedback

[1] Efron, Robert. "The minimum duration of a perception." Neuropsychologia8.1 (1970): 57-63.
[2] Kandel, E. R., Schwartz, J. H. 1., & Jessell, T. M. (2015). *Principles of neural science* (5th ed.). New York: McGraw-Hill, Health Professions Division.

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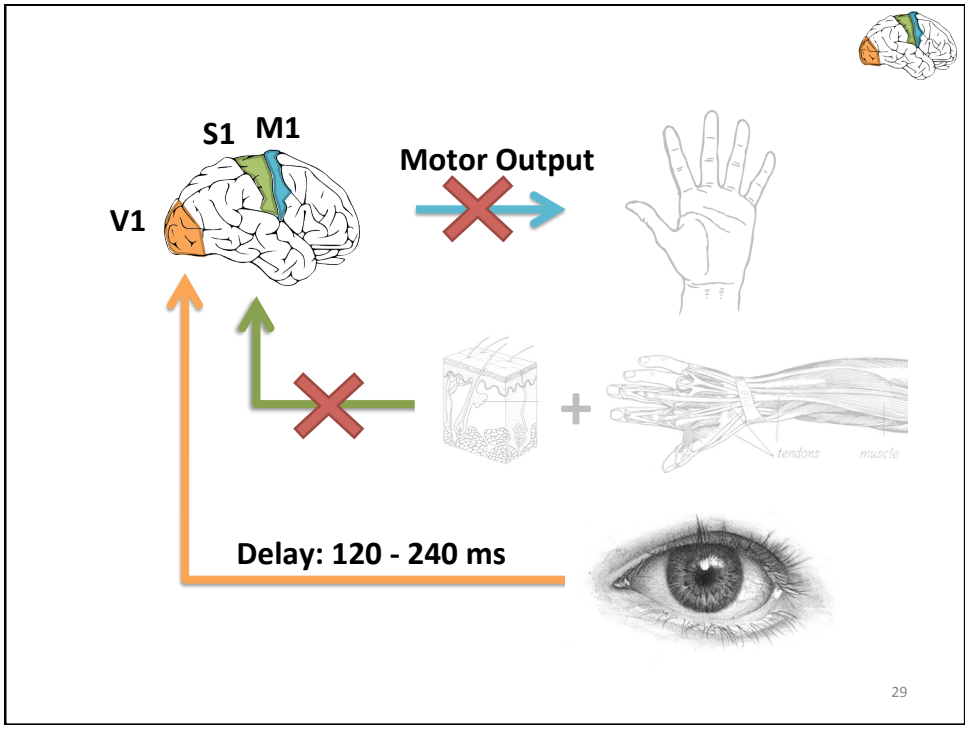
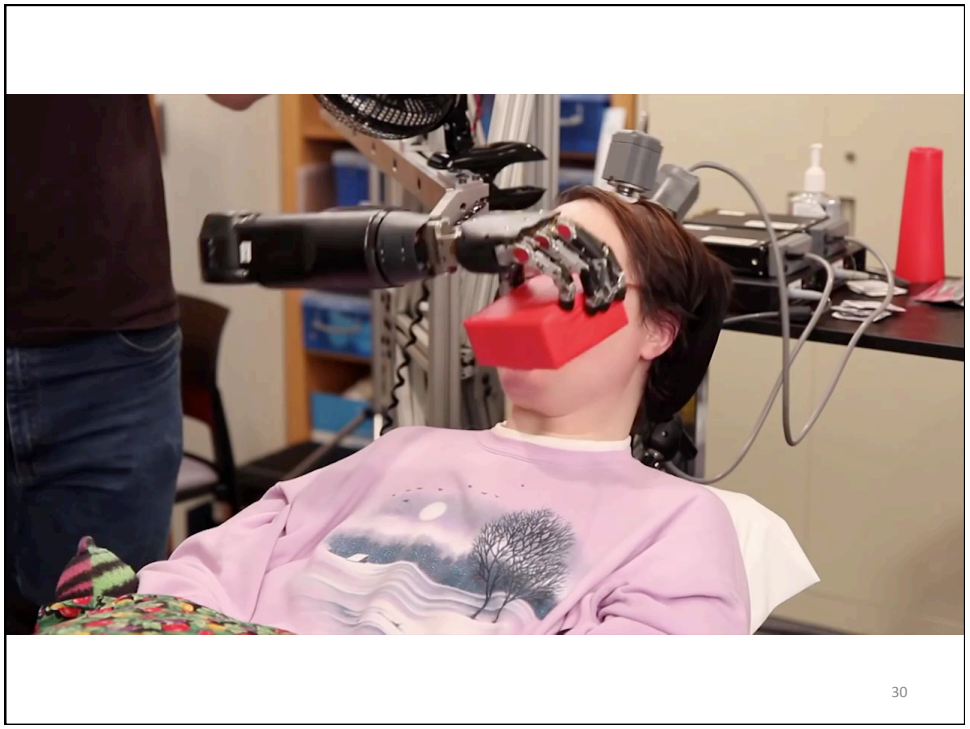
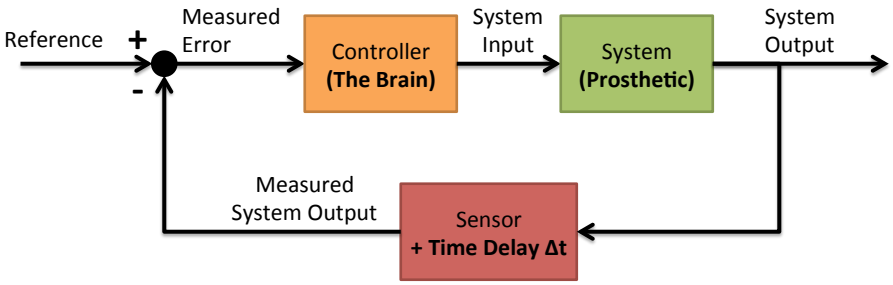

S1
M1
V1
Motor Output
tendons
muscle
Delay: 120 - 240 ms
29


30

Classic Feedback System



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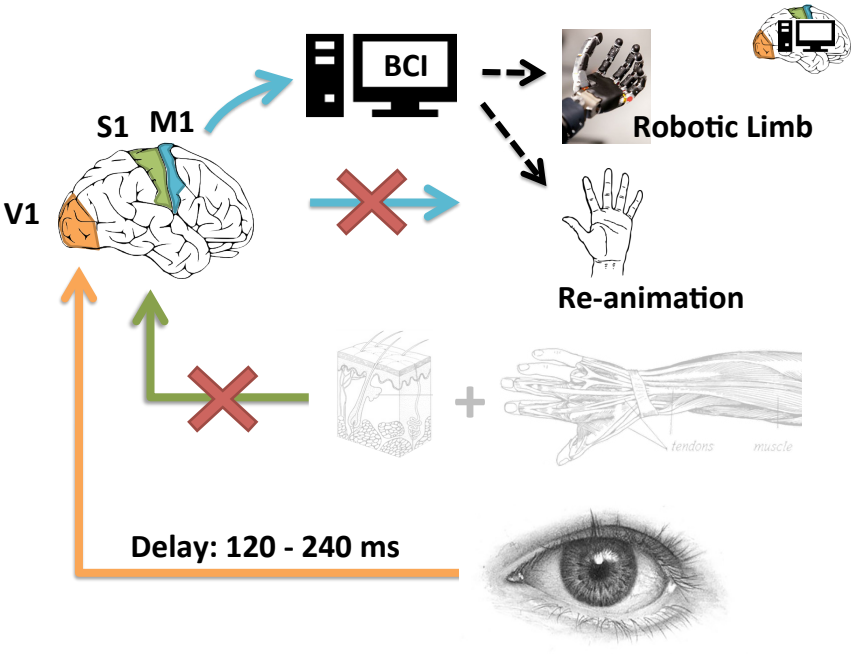

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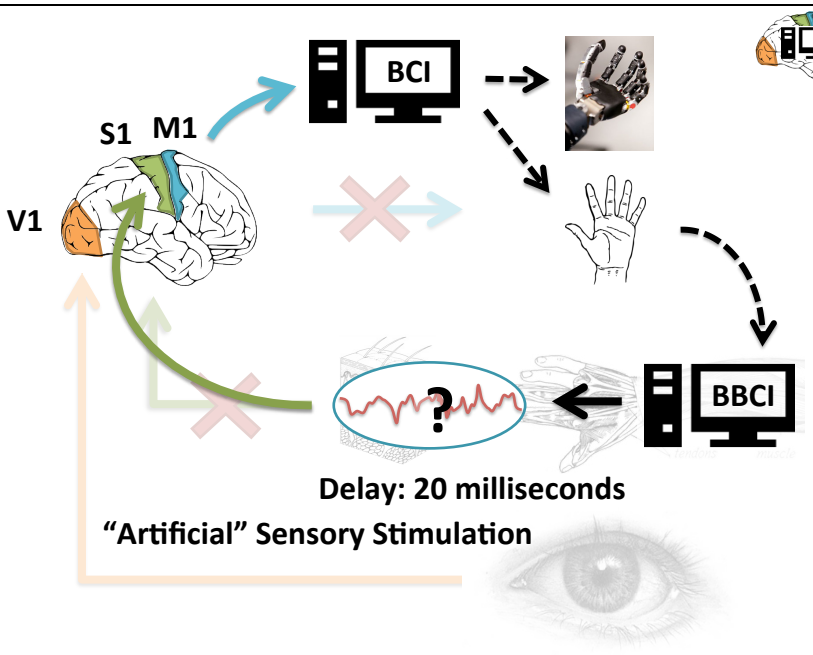
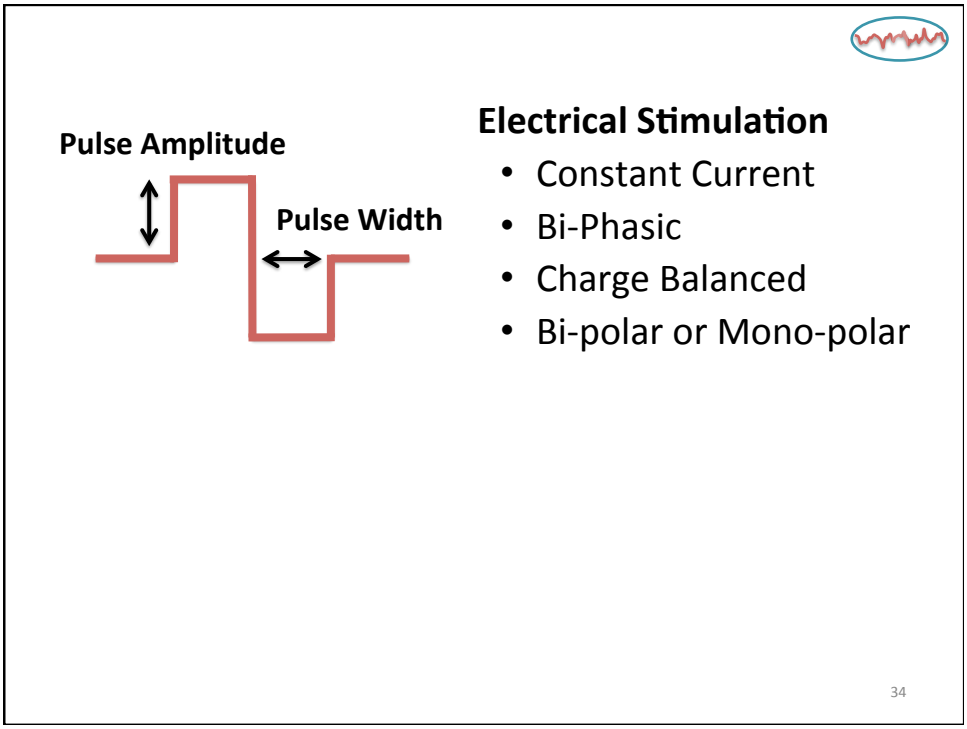
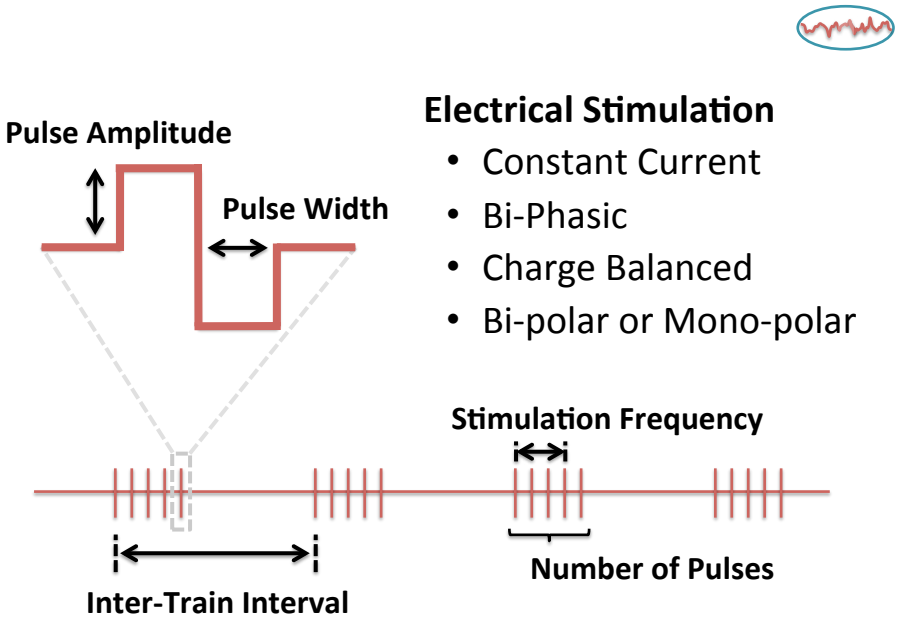
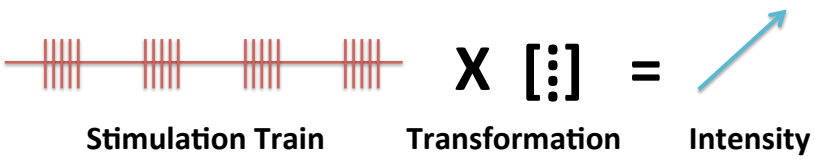
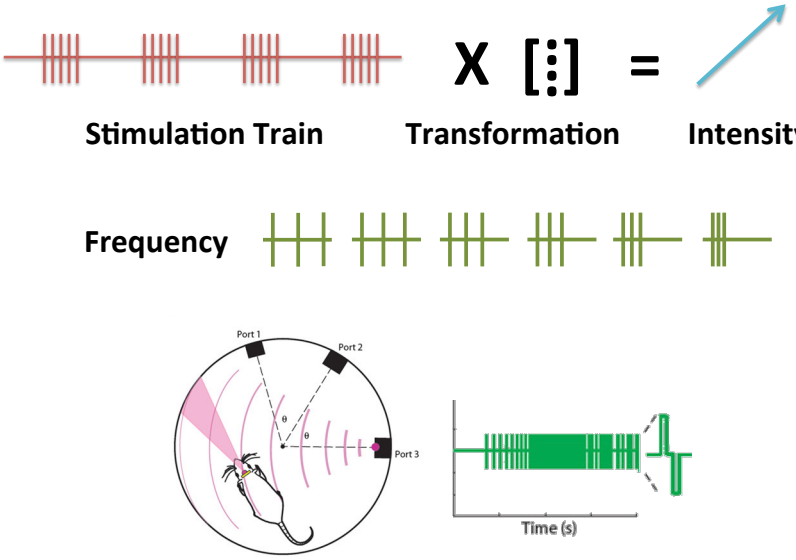

BCI
S1
M1
V1
?
BBCI
Delay: 20 milliseconds
"Artificial" Sensory Stimulation
33


Pulse Amplitude
Pulse Width
Electrical Stimulation
• Constant Current
• Bi-Phasic
• Charge Balanced
• Bi-polar or Mono-polar
34


Pulse Amplitude
Pulse Width
Electrical Stimulation
• Constant Current
• Bi-Phasic
• Charge Balanced
• Bi-polar or Mono-polar
Stimulation Frequency
Number of Pulses
Inter-Train Interval
35


X [⋮] =
Stimulation Train
Transformation
Intensity
36

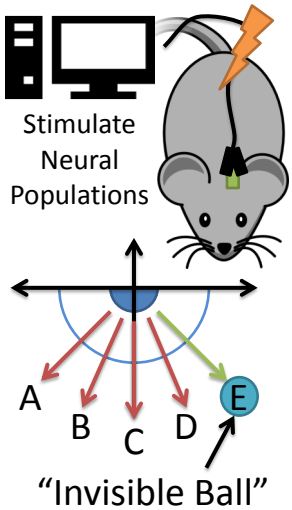


37

Thomson EE, Carra R, Nicolelis MA (2013). Perceiving invisible light through a somatosensory cortical prosthesis. Nat Commun. 2013;4:1482. doi: 10.1038/ncomms2497

Aim 1: ACRoBaT

(**A**utomated **C**enter-out **Ro**dent **B**ehavior**a**l **T**rainer)



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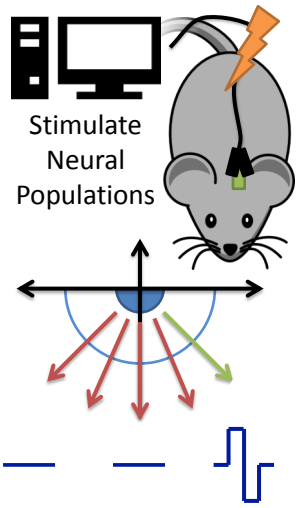
Aim 1: ACRoBaT

(**A**utomated **C**enter-out **Ro**dent **B**ehavior**a**l **T**rainer)



Perceptual Thresholds

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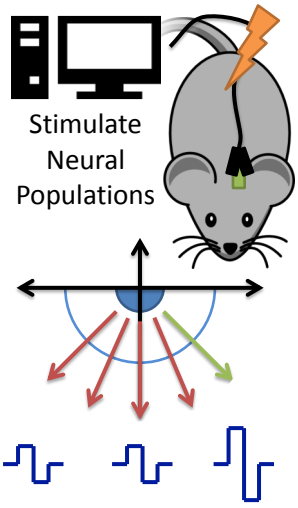
Aim 1: ACRoBaT

(**A**utomated **C**enter-out **Ro**dent **B**ehavior**a**l **T**rainer)

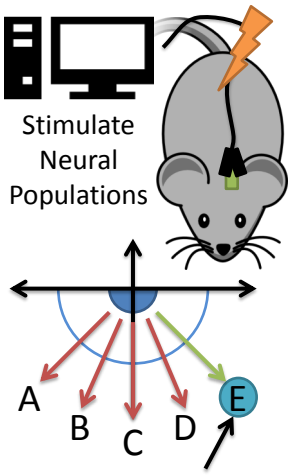


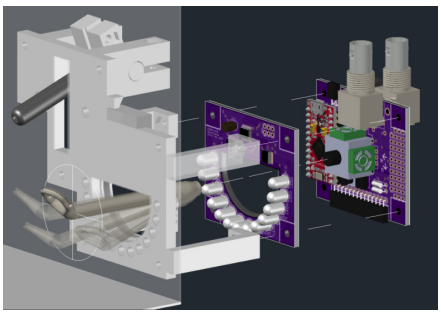
Measure Discriminability

40

Aim 1: ACRoBaT

(**A**utomated **C**enter-out **Ro**dent **B**ehavior**a**l **T**rainer)





- Modified Center-out Task
- Complex Behavioral Task
- High Throughput Training
  - 23 Training Levels (4 Phases)

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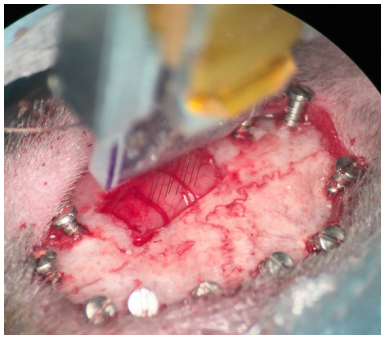
Surgical Methods

- Intra-Cortical Micro-Stimulation (ICMS)
  - 16 Channel
  - Hand Built
  - Tungsten micro-wire
  - 30 µm diameter
  - 100 – 500 kOhms

ICMS



- Implanted in sensory-motor cortex
  - Targeting layer 5, depth 1.5mm

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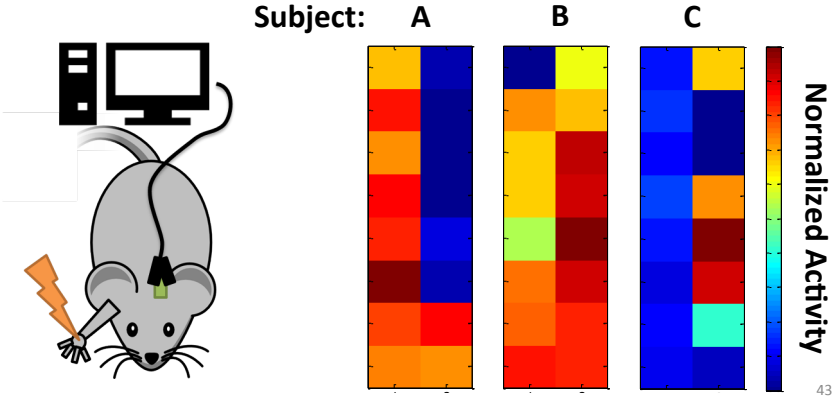
Sensory Evoked Potentials

- Validate Location of the Implant
- Evoke Sensory Activity via Muscle Twitches
- Chose Electrode Sites with some activity, but avoided the maximum responding site



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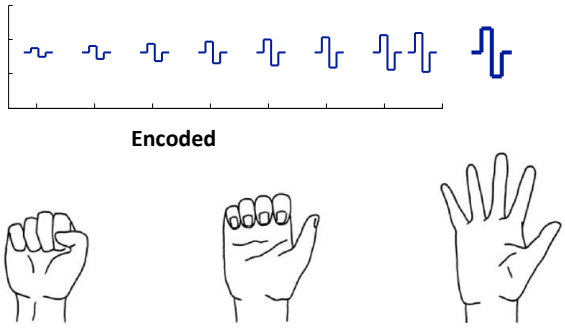
Just Noticeable Difference (JND)



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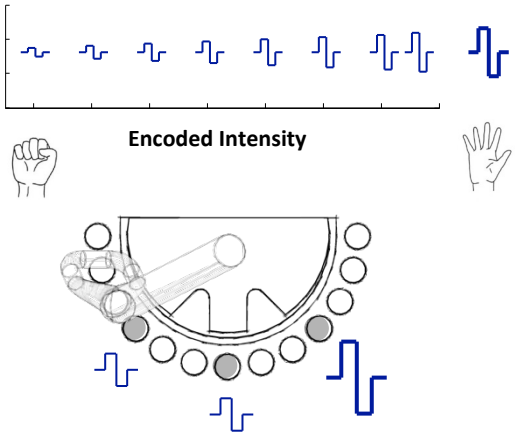
Just Noticeable Difference (JND)



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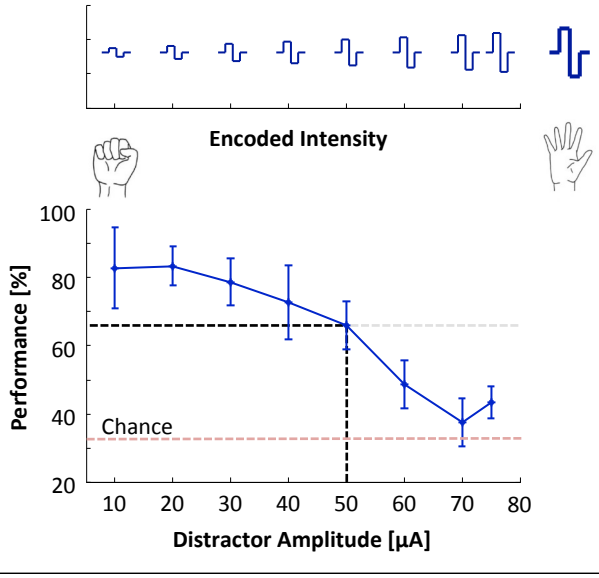

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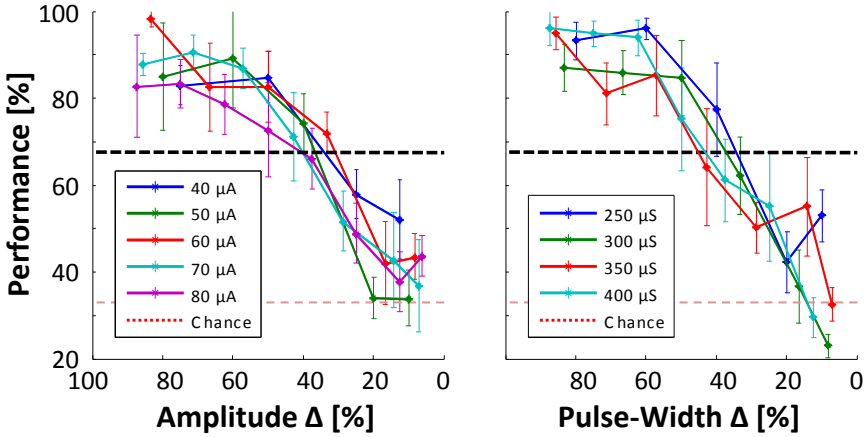
Results



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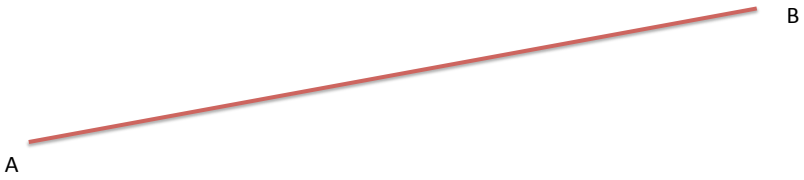
failure



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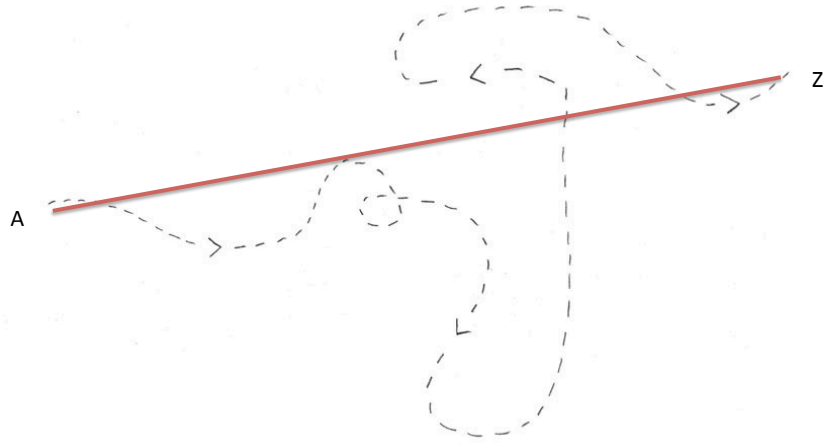
failure



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the end

- engineering = problem solving
- learn how to solve many different problems
- apply those tools, many different places
- have a lot of fun

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