Transduction and Output

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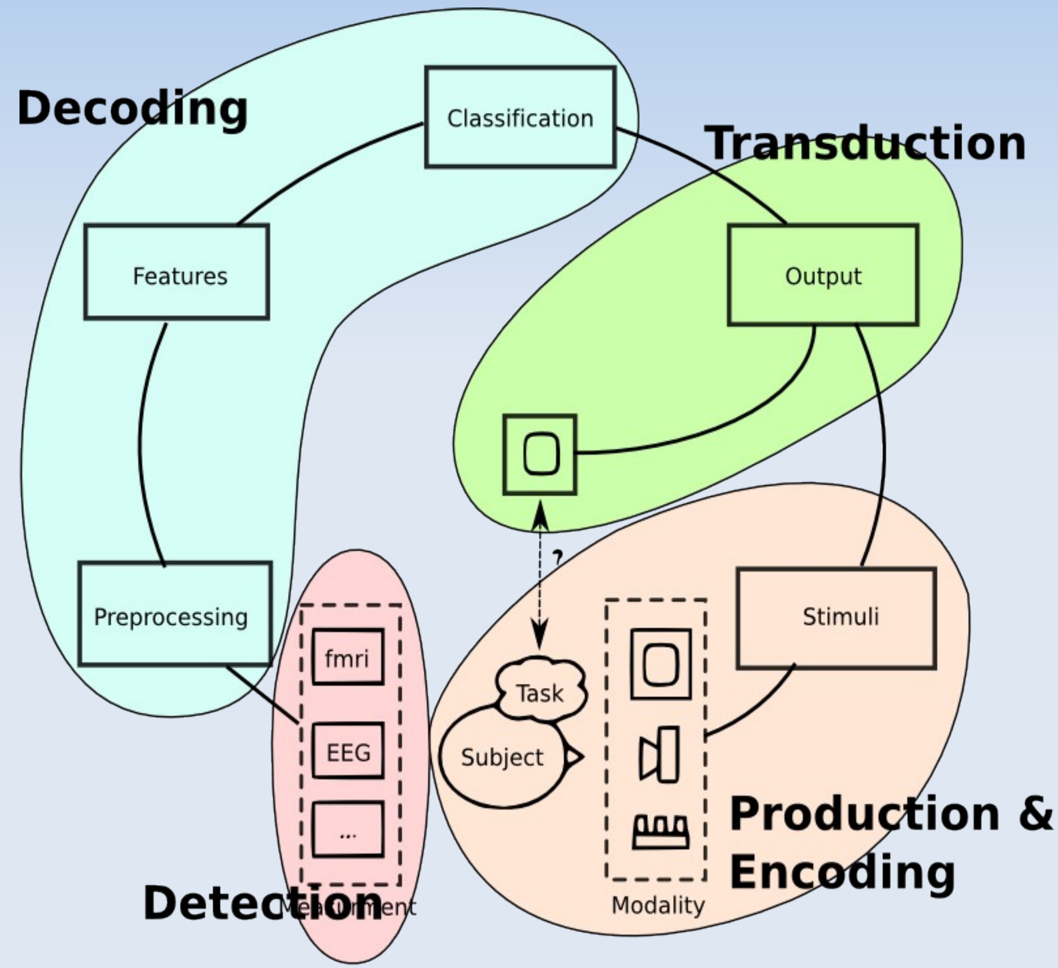
The BCI Cycle

1) Signal Production: Get the person to produce a strong brain signal,either by performing an explicit mental-task, or through normal mental processes (2,6,7,8)

2) Detection: Build a machine able to directly measure the properties of someone's brain, e.g. EEG, MEG, fMRI (3)

3) Decoding: Build a machine able to decode the measurements to deduce the users mental state (4)

4) Transduction: Communicate the mental-state to the outside world (5)



Learning Goals

- Understand the purpose of the output stage of BCI
- Understand how the key properties of BCI based communication, i.e. unreliable, low-bit-rate, high-latency, influence the design of the output system
- Understand how contextual information can be used to overcome these limitations
- Be able to describe the output-designs which have been developed for spelling systems, including; p300-visual-speller, TTD, Graz-virtual-keyboard, etc.
- Know what a systems bit-rate is, why it's important for BCI, and what the important characteristics of the Wolpaw Information Transfer Rate are.

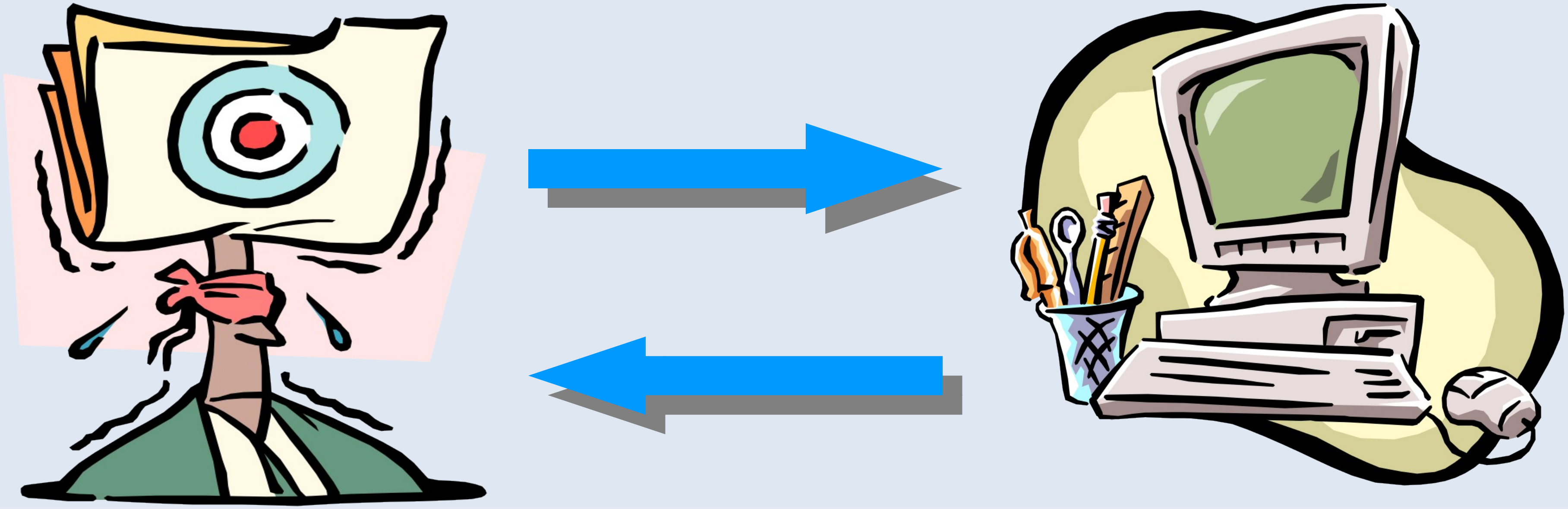
Output, System Integeration and HCI

- In principle output is easy –
  - Simply transform the decoded intentions into the requested task
- However, practical BCI does not exist in isolation
- It just provides the pipe which allows the user to communicate with the computer....
- … to achieve some higher level use objective, e.g. Send a letter, turn-on-a-light

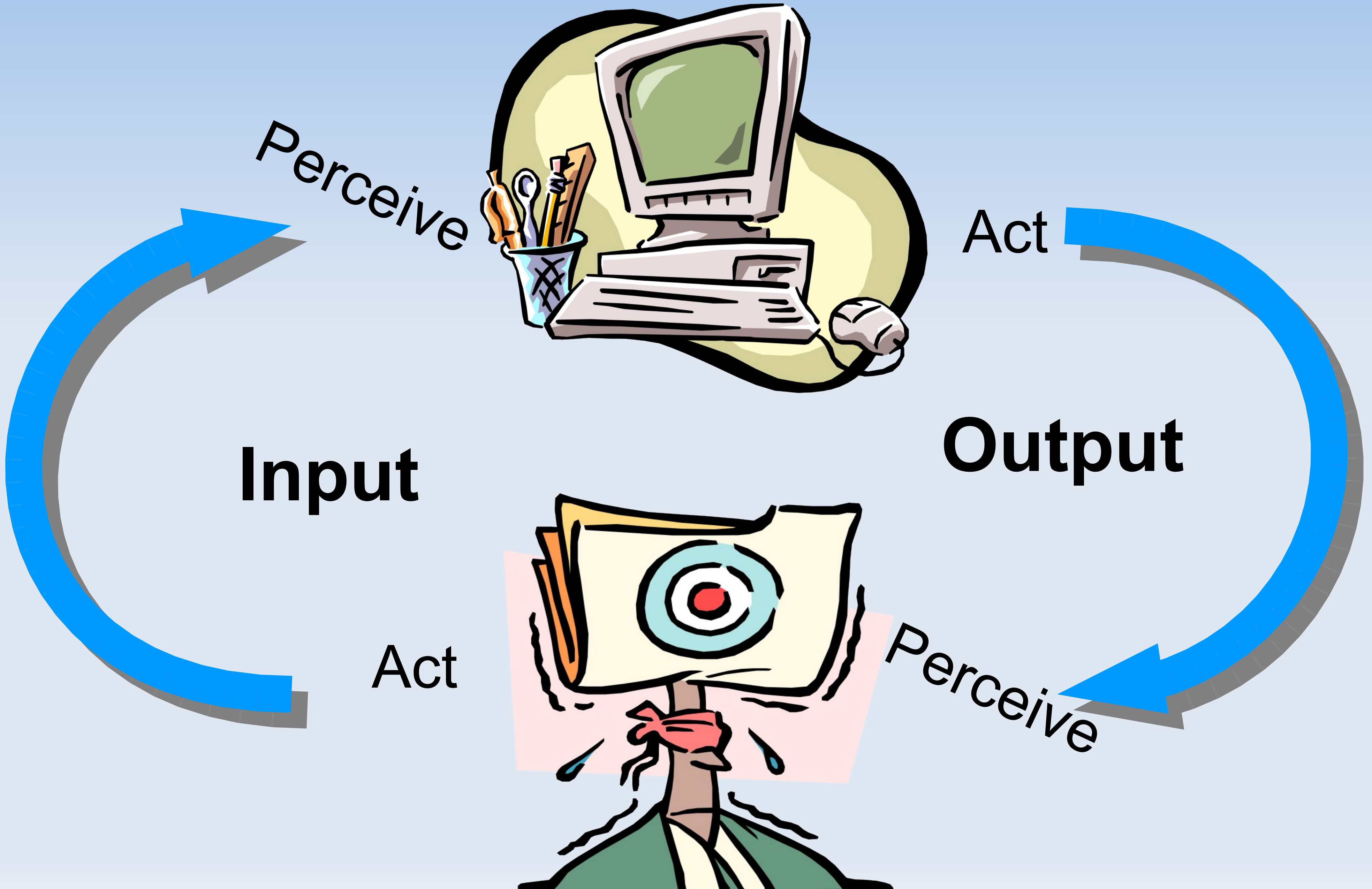
BCI must be integerated within the larger
Human Computer Interaction
system to build a practially useful system

Human Computer Interaction

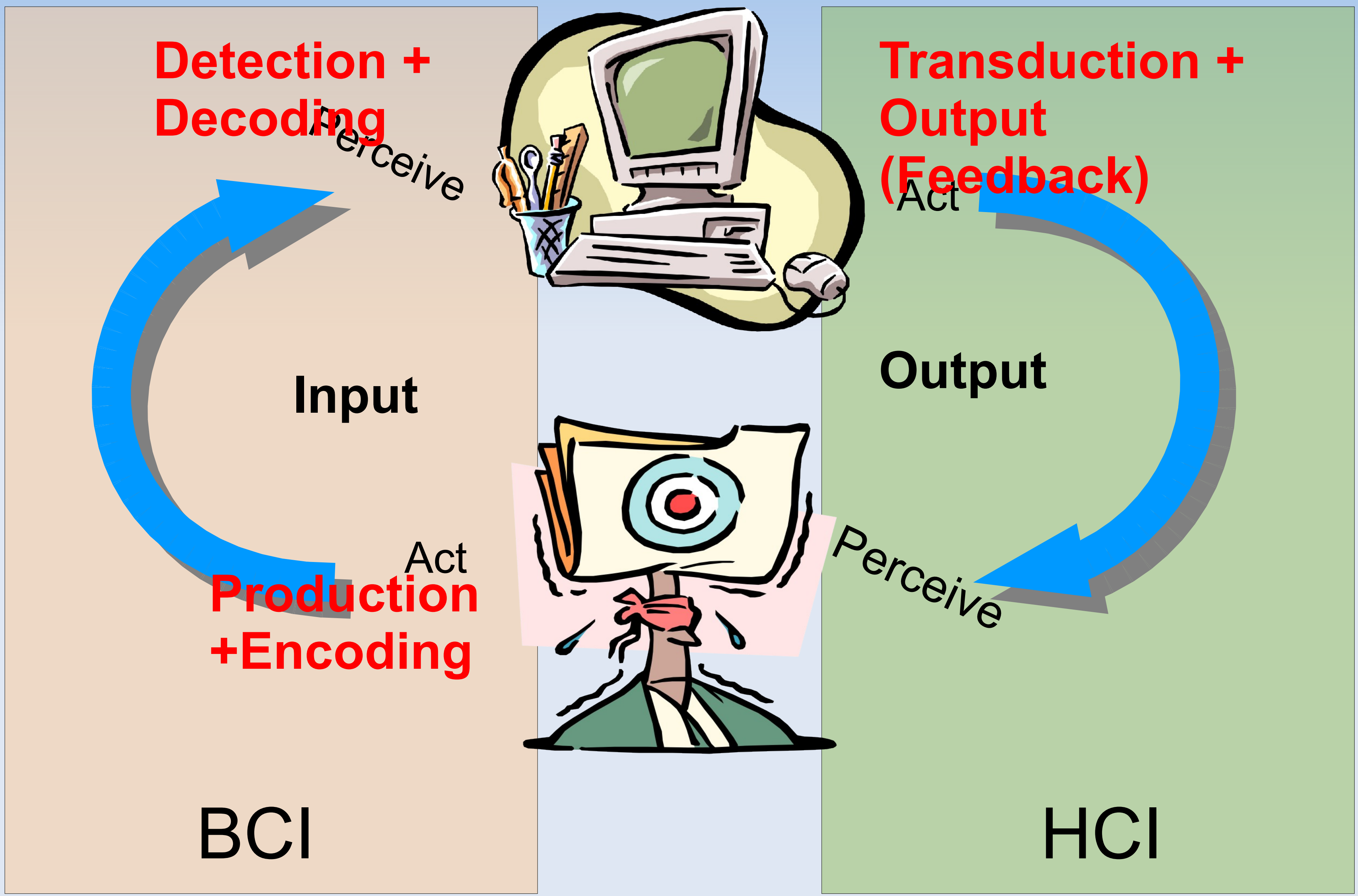
- User has some request/task in mind
- How can the user (learn to) communicate this to the computer?
- How can the computer understand the actions of the user?



What is interaction?



Human (Brain) Computer interaction?



BCI/HCI

- HCI not usually the focus of BCI research...
  - … HCI specialists are much better at it!
  - … just getting signals out of users heads is hard enough.
- However, being aware of the HCI issues can help to;
  - Make best use of limited communication possible
  - Make communication as easy as possible

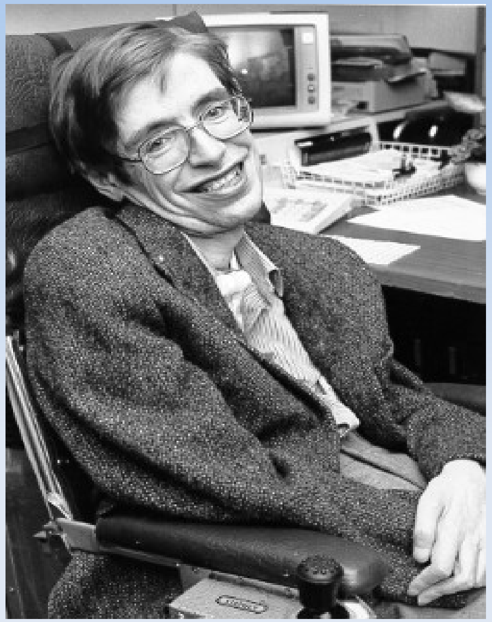
Goals of good HCI

- Easy to use
  - For the target user group!
- Easy to learn
  - Stimulus-response compatability → (when possible) select mental tasks which corrospond well to the task the user wishes to perform
- Efficient and effective
  - Few actions necessary to perform task → use contextual information to reduce the number of possible messages

Potential User Groups

- The healthy
  - Occupational or for entertainment
  - Useability more important than strictly using brain signals
- The handicapped
  - Specific deficits: prosthetic limbs vs communication
  - Varying durations of use
- The completely locked in
  - End-stage ALS, Guillain-Barré syndrom
  - Generally not a long life expectancy
  - Benefits of early exposure to the paradigm/ system

Target users: ALS patients



- Cognitive function in ALS patients:
- 50% show signs of fronto-temporal dementia (FTD):
  - attention deficits
- Depends on type of ALS (bulbar onset: 50% more likely)
- Altered ERP responses
- Visual P1 absent, BAEP’s appear normal
- Altered motor processing
  - Long immobility
- Higher incidence of mood disturbance/ depression

Abe et al (1997), Haganasi et al (2002), Münte et al (1998), Onofrj et al (1997)

Stimulus Response Compatibility

- Feedback should in some way be compatiable with the user actions (mental tasks),
- Makes the intentional encoding easier for the user to remember
  - e.g. Left-hand=move left, right-hand=move right, foot=move forward
  - Concentrate on the intended letter
- Note: Limited number of mental tasks available to particular user makes this difficult in many cases.

Contextual Information

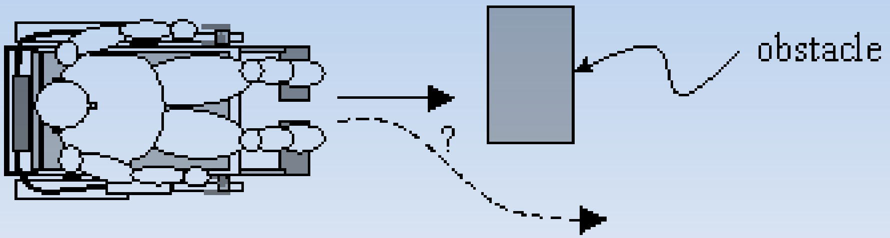
- Contextual information can be used to reduce the bit-rate requirements on the communications channel
- Allowing the system to infer likely intentions..
- .. hence reducing the effective number of messages to be sent

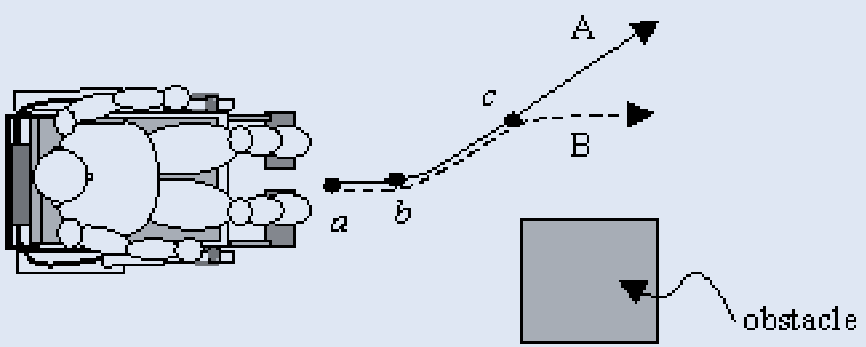
Contextual Information

- Language models in spelling systems, e.g. T9
- Pointer momentum in 2D cursor control
- Interaction dialog (invalid states) in button navigation
- Conservation tree in dialog systems, e.g. Re-phrase

Context and shared autonomy

- Does the user intend to hit the object (gently)?
- Should the wheel-chair take-over?
- Mental Augmentation through Determination of Intended Action (MAIA)





BCI limitations

- Unreliable, high noise
  - 1 mistake every 10 yes/no decisions is very good (90%)
- High latency
  - <3s per yes/no decision is considered good
- Low bit-rate
  - 90% @ 3s = ~3cpm

Similar limitations as other comminication systems,
e.g. Disabled users, PDAs.
Hence, use interfaces developed for these systems

Bit-Rate / Information Transfer Rate

- ITR is a more useful measure of BCI performance than just classification rate.
- It also takes the time per classification and number of classes into account.
- Many definitions used for ITR, but for BCI, the Wolpaw definition is mostly used (Wolpaw, Rosamer, McFarland, & Pfurtscheller, 1998).

Information Transfer Rate

$$B = VR$$

$$R = \log_2(N) + P\log_2(P) + (1-P)\log_2\left(\frac{1-P}{N-1}\right)$$

- B = bit rate in bits per second
- V = classification rate, classifications per second.
- R = Bits per classification
- N = number of classes
- P = probability that the classifier is correct

Example Information Transfer Rates

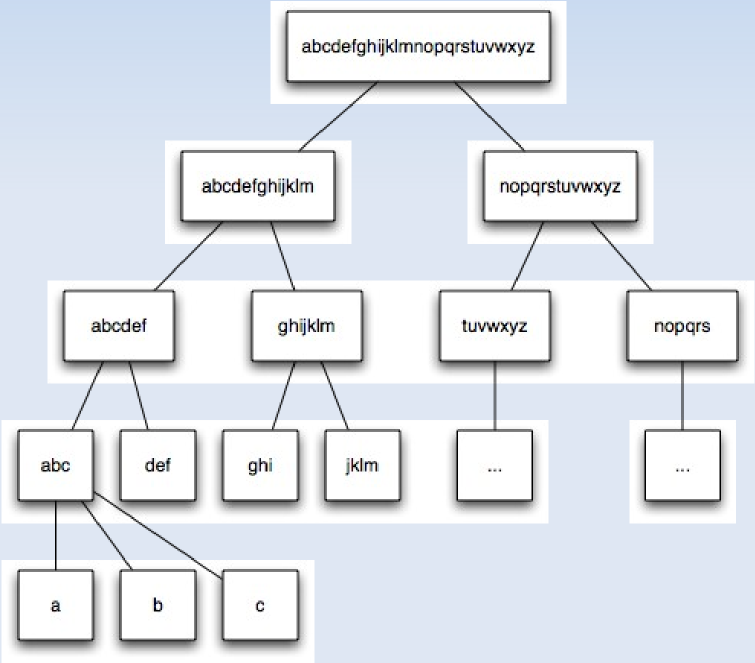
- Keyboard: 60wpm = 240cpm
- Mouse: ~80cpm
- Phone Keyboard (multitap): ~25cpm
- Phone Keyboard (T9): ~50cpm

- BCI (best ever!): ~40cpm (Geuger p300)
- BCI (average): 2-5cpm

Example BCI/HCI designs: Speller systems

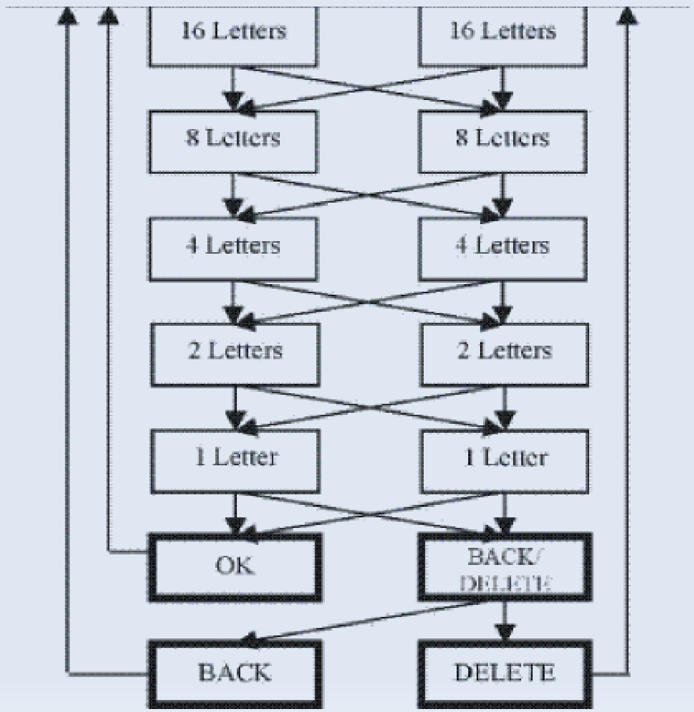
- User Task: Write sentences in natural language

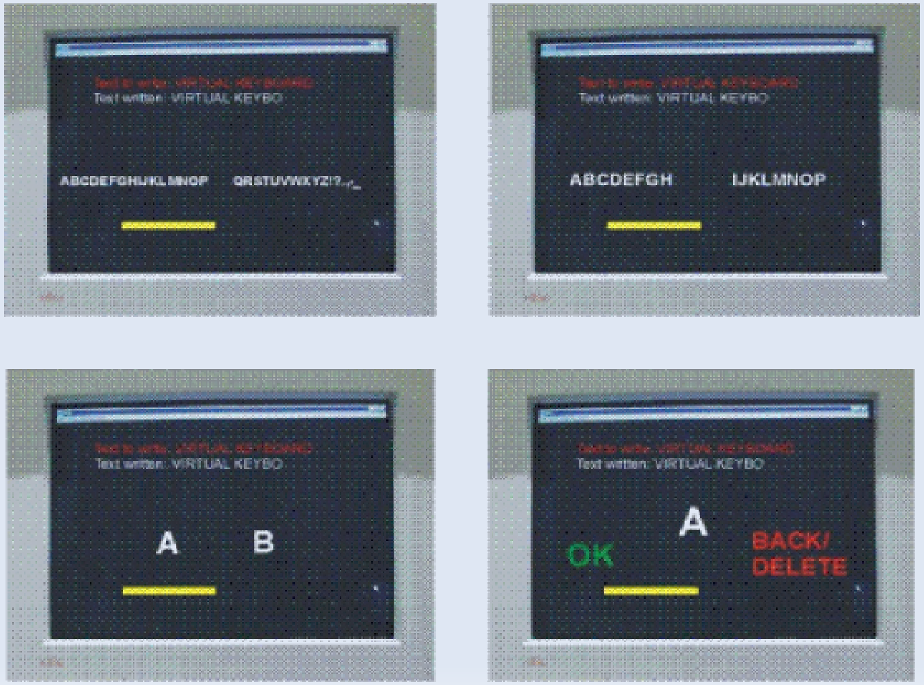
- Design Characteristics
  - Character encoding – decision tree?
  - Intentional encoding?
  - Contextual Information – language model?
  - BCI specific?
  - ITR?



Graz Virtual Keyboard

- Character encoding: decision tree
- Intentional encoding:
  - left-hand=left box, right-hand=right box
- Contextal awarness: none
- ITR: 0.67-1.02 cpm (healthy subjects)

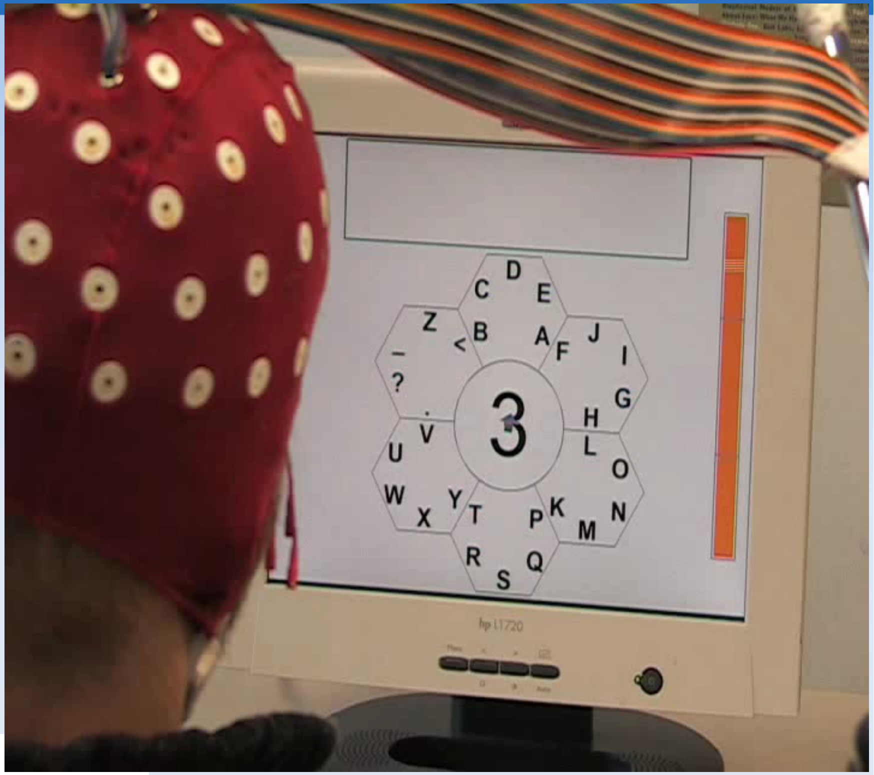


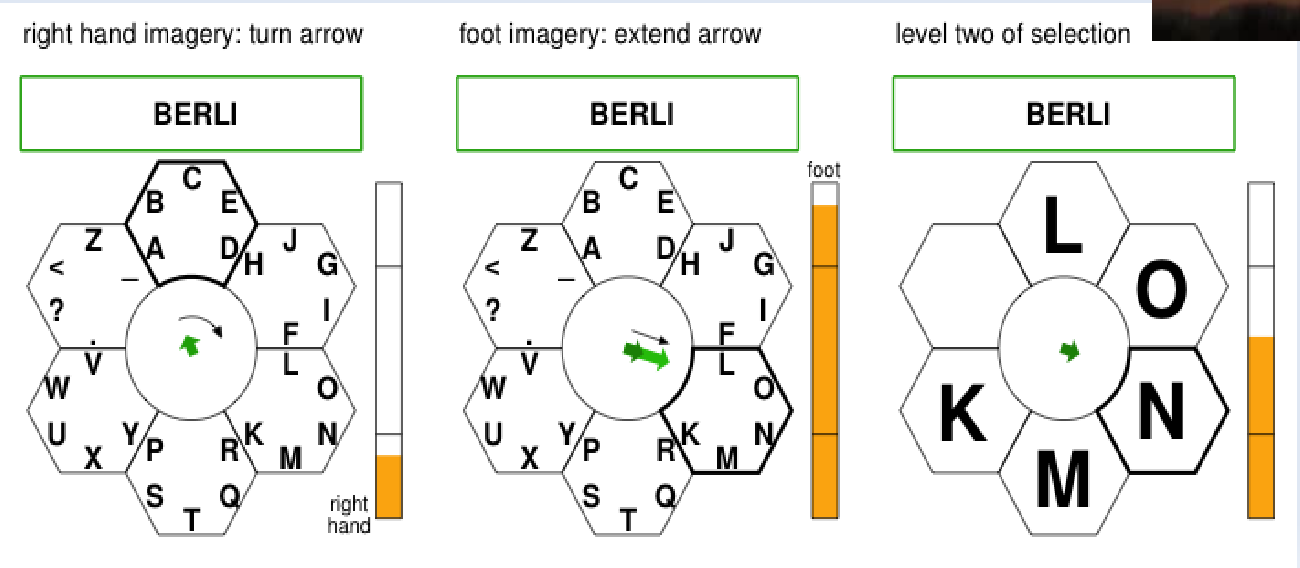


Obermaier et al. 2003

Hex-O-Spell

- Character encoding – decision tree
- Intentional encoding
  - right-hand=rotate arrow
  - foot=extend arrow
- Contextual Information
  - Prediction by partial match (PPM) to order level two letters
- Adapted from PDA speller interfaces
- ITR – 2.3 to 7.7 (healthy subjects)

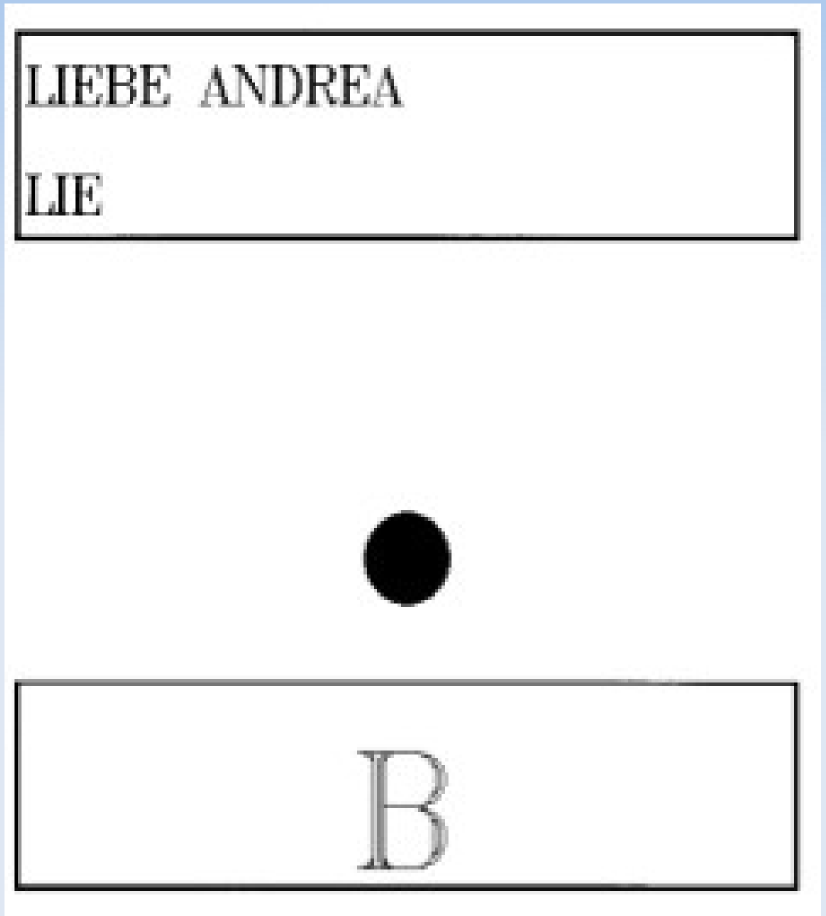




Blankertz et al. 2007

Thought Translation Device (TTD)

- Character encoding
  decision tree
- Intentional encoding
  - SCP voltage = cursor position
- Contextual Information – none
- ITR – 0.5 cpm (locked in patients)

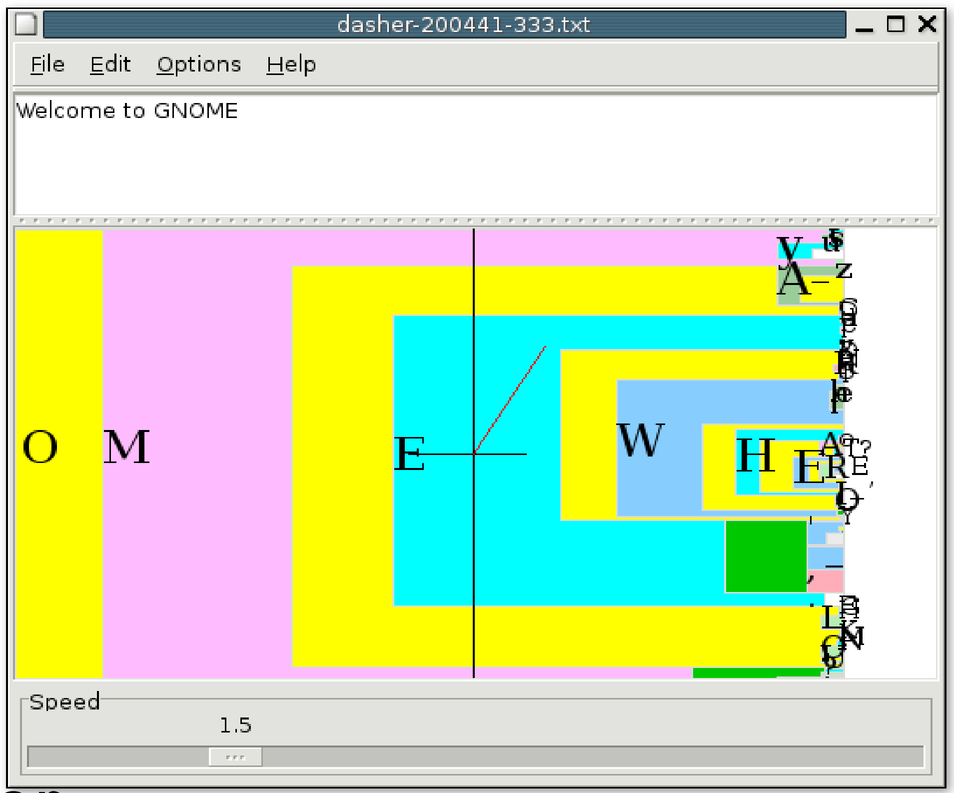


Birbaumer et al. 2000

Dasher

- Developed for PDAs
- Character encoding

  decision tree
- Intentional encoding
  - LH=cursor up, RH=cursor down
- Contextual Information –
  - Language model → character size
- ITR – 5-6 cpm (healthy users), 0cpm (patients)



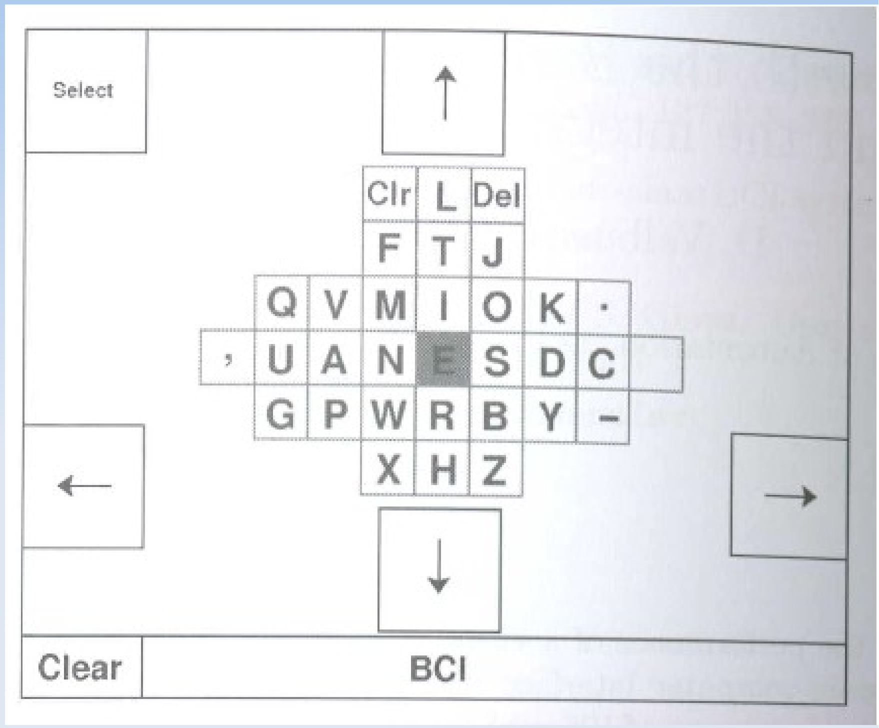
Ward et al. 2000

Dasher

Interface

Bremen BCI Speller

- Developed for BCIs
- Character encoding
  - decision tree(ish)
- Intentional encoding
  - Visual SSEP
  - Attend L/R/T/B=move L/R/T/B
- Contextual Information –
  - Letter frequency → character positio
- ITR – 2.1 cpm (healthy users)



Friman et al. 2007

Classic P300 Visual Speller

- Developed for BCIs
- Character encoding - direct
- Intentional encoding
  - Visual p300 response
  - Attend symbol=select symbol
- Contextual Information – none

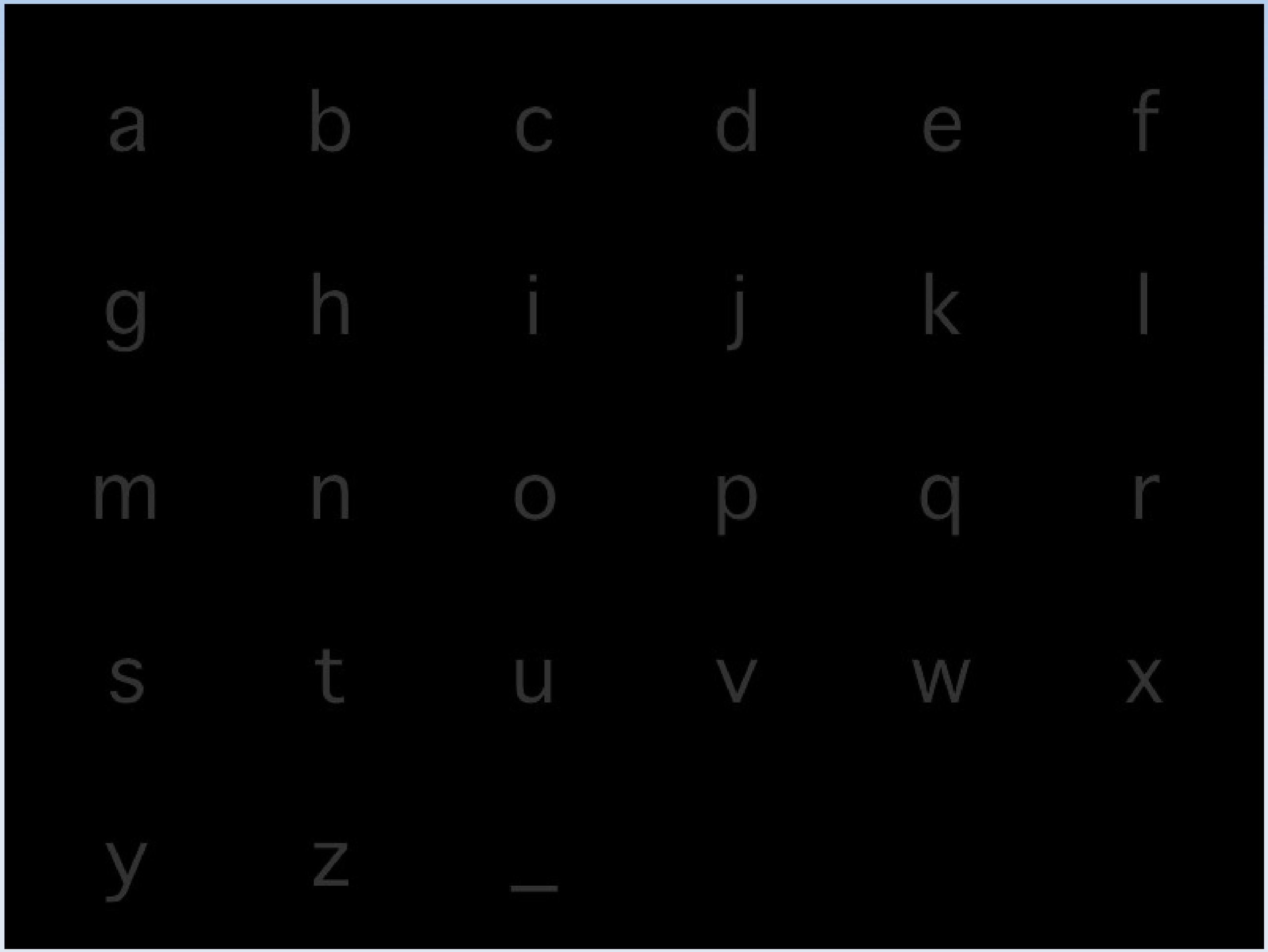
Choose one letter or command

A	G	M	S	Y	*
B	H	N	T	Z	*
C	I	O	U	*	TALK
D	J	P	V	FLN	SPAC
E	K	Q	W	*	BKSP
F	L	R	X	SPL	QUIT

- ITR – 2.3 cpm (orginal healthy users),
- Many refinements; language model, stimulus type, flash sequence, etc. → ITR up to ~30cpm (fast best subject)

Farwell & Donchin 1988

P300 Visual Speller



Summary

- The output stage of the BCI is primarily concerned with HCI issues, e.g. Ease of use, ease of learning, stimulus compatability
- The unreliable, low-bit-rate, high-latency, nature of BCI mean the system must be designed for these properties
- Contextual information can be used to reduce bit-rates
- BCI designs used for spelling include; p300-visual-speller, TTD, Graz-virtual-keyboard, Hex-o-spell, etc.
- Information Transfer Rate (ITR) gives a better idea of a BCIs usefulness than classification rate alone

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Postscript:
BCI Paradigms – most common

- SCP's: trained features
  - Much training needed
  - Arbitrary feature can be chosen
- Motor imagery (lecture 6)
  - Arms/ hands, feet, tongue
  - Self-paced vs cued
- Selective attention (lecture 7)
  - P300
  - SSEP
  - Different modalities

BCI paradigms: the more creative

- Spatial navigation
  - Focus on navigation & details in surroundings, not walking
- Auditory imagery
  - Generally used irrespective of which song is imagined
- Internal arithmetic
  - Non-trivial calculations
- Word generation
- Sensorimotor attention
  - Attend to a body part without thinking of moving it
- Visual imagery
  - Geometric figure rotation

BCI paradigms: the radical

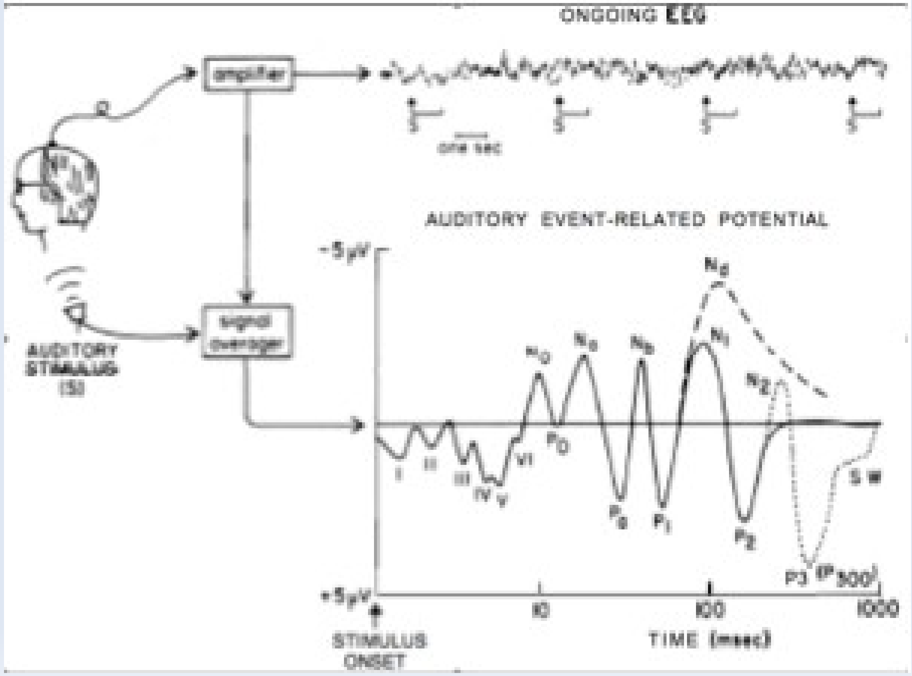
- Approach/ reject
  - Either empathize (out-of body sensation) with the avatar or want it to go away
- Imagined letter-writing
- Imagery of words/ concepts
- Meditative states?
- Emotions?
- Etc..!

EEG/MEG mental signatures

- ERPs: event-related potentials, low frequency effects
  - Polarity (@certain position)
  - Latency
  - Amplitude
  - Distribution over the scalp
- Time-frequency responses, high(er) frequency effects
  - Range (α–, μ–, β–, γ–band, subdivisions)
  - Evoked/ induced
  - Direction of relative change (ERD/ ERS)
  - Latency
- Coherence: phaselock without amplitude change

ERPs

- Some known components:
- Pre-stimulus:
  - Readiness potential (RP)
  - Contingent Negative Variation (CNV)
- Post-stimulus:
  - Early ‘physical’ & later cognitive processing
  - Modality-specific
    - N100
    - P200
    - N200 / MMN (Nd)
    - P300 (P3a and P3b)
    - N400
- Post-response:
  - Error Related Negativity



Time-Frequency Responses

- δ-, θ-, α-rhythms
  - slow-wave sleep, meditation, idling
- μ-, β-rhythms
  - Normal waking consciousness
  - Motor activity/ imagination, general concentration
  - In excess: anxiety
- γ- rhythms
  - REM-sleep
  - Perception, perceptual binding
  - Short-term memory
  - Attentional processes
  - Etc...
  - BUT: Increasing evidence for artifact sensitivity
    - (Yuval-Greenberg et al ‘08, Whitham et al ‘08)

Prediction by Partial Match

- PPM(n) uses the n previous characters to predict the next.