Dynamics and Interaction in BCI: Shaping the Interaction Control Loop with Uncertain Inference

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Outline

1. The Interaction control loop
   - Interaction design for probabilistic inputs
2. Mobile interaction examples
3. BCI applications
4. Outcomes and plans
What **HCI** can offer **BCI**
(and vice versa)

- **For BCI**: opportunities to design interfaces which can improve quality of interaction
  - Can offer benefits without having to change underlying system

- **For HCI**: offers an unusual and compelling testing ground for new interaction ideas
  - Highlights where conventional *ad hoc* techniques break down
Interaction with inferred inputs

- We are adding more rich sensing to our machines, and machine learning has a lot to offer, e.g. context-aware systems, gesture recognition
  - But how should we design the interaction?
- E.g. in BCI, lots of work on better classification algorithms
  - Less work on more suitable interface designs
- Should not treat a BCI as if it were a mouse!
  - Build appropriate interfaces for determining intention
Example applications

- Mobile, motion-sensing, Brain-Computer Interaction, and location aware systems
Goal Spaces

• We focus on the problem of interaction with sensors producing continuously varying measurements.
• The interaction is a closed-loop control process and the ultimate control variable is the distribution over actionable goals.
• The purpose of the system is to perform recursive evidence updates to infer the new goal distribution, forming a trajectory through the space of distributions. The space in which this trajectory lies is the goal space;
• For example, discrete selection: $p_1...p_n$ simplex in $n$-d space
  – Inference (should) result in a smooth trajectory in this space
  – Large steps in entropy are unnatural & error-prone
  – Information rate determines smoothness
• Give feedback to user about progress through this space. By avoiding discrete state changes as long as possible, the need for after-the-fact correction system such as undo can be minimised.

**Figure II.5:** The changing entropy $H(x)$ across regions of the goal space, shown here for a three goal system. Entropy is shown as the dotted surface above the simplex — distance from the surface indicates entropy at that point. It reaches its maximum of 1.584 bits at $\langle \frac{1}{3}, \frac{1}{3}, \frac{1}{3} \rangle$, and drops to zero at the vertices.
Evidence, Goal and State spaces
Interface Dynamics

• Control theory perspective
  – We have evolved to control our perceptions. We require feedback, and there are upper limits on our bandwidth.
  – User interacting with interface object viewed as two coupled dynamic systems
  – Physical model-based approach to representation of interface objects
  – Dynamics allows us to slip in ‘intelligence’ into the closed-loop which couldn’t be done with a static interaction technique

• Probabilistic perspective – uncertain interaction
  – Uncertainty in user’s mind about what to do next, and system uncertain about user’s intentions.
  – Dynamics and feedback are adapted based on probabilistic inference.
  – Taking explicitly Bayesian view. Probability distributions will be assigned to beliefs in a system.
  – Joint system dynamics mediate the flow of evidence between participants at an appropriate rate.

• Multimodal, embodied perspective
  – Coupling and interaction is continuous (time and space) and feedback is multimodal.
  – Interaction is active – energy in, information out.
Particle GPS Browsing

- Location-aware audio & haptic feedback
- Use tilt and bearing to get rapid exploration
  - Project forward, find likely locations in the future.
- Map browsing; include uncertainty about where we are
  - Show all the possible places we might be, given a map of the area
  - User can scan around and project further into the future.
- Augmented reality content is interpreted by models which generate multimodal feedback
Shoogle - Informative Shaking

- Shake the phone to feel (and hear) content discreetly
- Only produces feedback when stimulated
- Simple physical model of objects in a box  
  - Movement from accelerometers
- Impact with edges produces sound and vibration
**Message Box.** The user reaches into a drawer, and shakes the device, without removing or looking at it. The contents of an SMS inbox are transformed into virtual "message balls". As the user shakes, impacts are heard and felt as these balls bounce around.

**Keys in a pocket.** The user carries the phone in a pocket while walking. Motion from the gait of the user is sensed by the accelerometers. As messages arrive, objects begin jangling around in the user's pocket, in a manner similar to loose change or keys.

**Liquid battery life.** The user shakes the device to gain a sense of its "fullness". When the battery is full, the sensation is like that of a full bucket of water sloshing around. As the battery drains, shaking the device sounds like a few droplets splashing, until finally all power evaporates. This is similar to the virtual maracas approach for resource sensing suggested by Fernstrom in [1].
Hex Entry: *Intelligent adaptation of handling qualities during interaction*

- Example gesture/word pairs
- Serves as example of continuous interaction system
  - with gestures & augmented control
  - ‘mechanism’ supported by hexagonal grid for feedback to user.

“Hello”  “GIST”  “Hexagons”
Augmented Control loops
BCI Work

• With the BCI group at Fraunhofer FIRST, Berlin
• **EEG BCI, using motor imagery**
  – Can be *trained very quickly* (20 minutes) and then used by novice users
  – One-dimensional cursor (usually)
  – Continuous control
BCI Interaction Issues

• Very asymmetric control loop
  – 4-40 bits/minute output and many orders of magnitude more input
Interaction Issues

- **Unusual signal properties** (for computer interfaces)
  - Long delays
  - Noise with varying structure
  - long-term **drifts**, event-related noise, stress effects...
Hex-O-Spell

- Simplified version of Accelerometer Hex
  - With PPM **language model**
  - Movement is rotation + forward
  - Characters **encoded as timing** of state changes
- World class text entry system for non-evoked potential
Uncertain Multiscale Multimodal Feedback

- Give the user a better understanding of classifier behaviour
- Classify on **multiple timescales** and show all of them
- Also show estimated **uncertainty** of cursor
BCI Interaction

- Introduce *appropriate* dynamics
  - Compensate for lack of physical dynamics
  - Interpretable model of inferential mechanics
- Better feedback
  - Display uncertainty
  - Multiple timescale estimates
  - Predictions
    - *Especially for learning*
- Use all available modalities
  - Visual
  - **Audio** – useful for “locked-in” patients
  - **Vibrotactile**
Multi-Class Liquid

- Instead of point cloud, create **liquid simulation**
- Move on space of potential possibilities
  - Goals at corners
- Dynamics are revealed by the blob's shape changes

Could also do multi-timescale, with blobs with excitable heads heaving tails behind.
Testing with EMG input
BCI SDAZ document browsing

- Tune dynamics to deal with tasks and signal characteristics
  - Dive modes, browsing modes, reading modes
  - Obvious utility for the motion impaired
  - Extend the expressive power of the limited inputs
- Include predictive displays
  - combine dynamics models with content models, e.g. Using particle filters
Interesting Possibilities...

• The Error Potential
  – Detect user awareness of error
  – Work out when things are going wrong and tune the dynamics appropriately

• Online workload adaptation...
The project was also involved in the organisation of the PASCAL BCI workshop at NIPS 2006, and at the PASCAL “BCI meets HCI workshop” held at IDIAP in Martigny, and the BCI PASCAL BCI thematic programme.

- Led to excellent interaction between mainstream HCI and BCI communities
- One quote from a leading BCI researcher was “We should have had this workshop 10 years ago!”
- http://www.maia-project.org/pascal-workshop
Outcomes

• Created one of the fastest non-evoked text entry systems in the world, and the novel approach to interaction was widely appreciated in the BCI community
• Liquid cursor concept was popular with BCI researchers, and has scope to represent uncertain, multi-scale inputs
• Uncertain interaction techniques also applied to mobile interaction, creating interesting opportunities for mobile augmented reality.

• Primed follow-on work:
  – Successful EPSRC proposal: 3 year Negotiated Interaction project.
  – Became a core part of the successful €9M TOBI (TOols for Brain-computer Interaction) proposal (FP7 Accessible and inclusive ICT).
  – Location-aware aspects part of the Hapmobili proposed EC project (with Nokia, Univ. Tampere, Polar…).
Pump-priming Publications


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