BCI practical course : “Hello World” & ERP Viewer

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Learning Goals

Understand:

- What is needed to make a BCI, i.e. progress tracking, data acquisition, annotation and processing, stimulus presentation, and an overall process scheduler/sequencer
- How to used event-driven programming ideas coupled to a global shared event pool (blackboard) to provide these facilities
- How the fieldtrip buffer provides the event blackboard which is used for inter-process communication.

Know how to:

- What the struct of an 'event' is and how to use it to annotate data with experiment relevant event information
- present simple visual stimulus/feedback to the user/experimenter
- How to wait for specific events, get the necessary data, process it and post the updated results back to the event blackboard
- Startup the buffer and an experiment control Matlab, and how to connect these processes to provide a basic BCI
- Test your experiment with simulated data generated by the signal-proxy
- Debug your experiment when it fails!

Today's Plan

- Discussion : What do we need to make a BCI?
- Introduction to the Buffer-BCI framework

break

- Hands-on 1: Hello World
- Hands-on 2: Sequenced Sentences

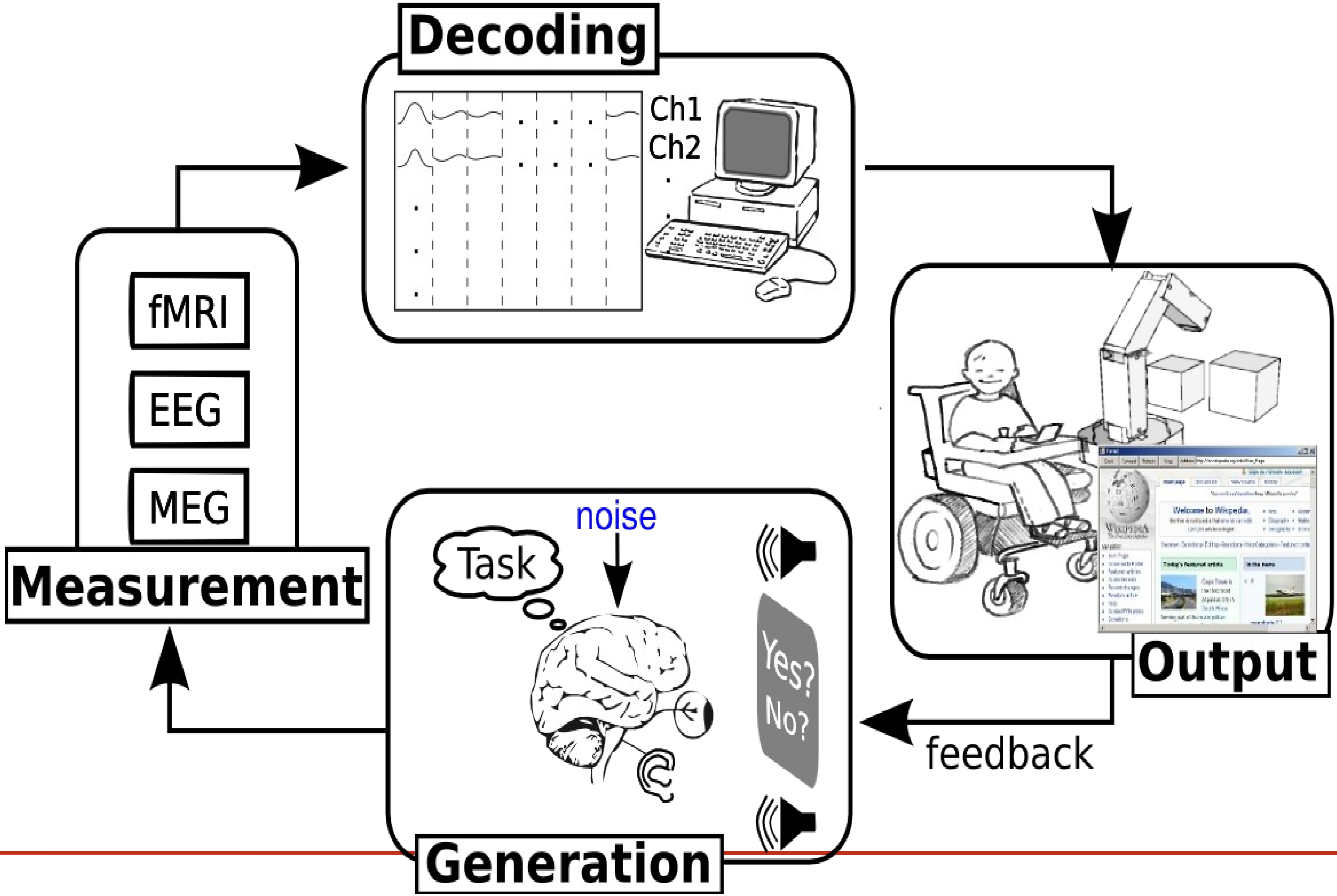
break

- Hands-on 3: Echo-server (event IPC)
- Hands-on 4: Visual ERP Viewer

Discussion: What do we need to make a BCI?

- Based on your prior knowledge and experience with the hands on demo we've did last time.
- Discuss: What do we require to make a BCI system?
- Think about:
  - Hardware requirements?
  - Software requirements?
  - Information flows?

BCI information flow

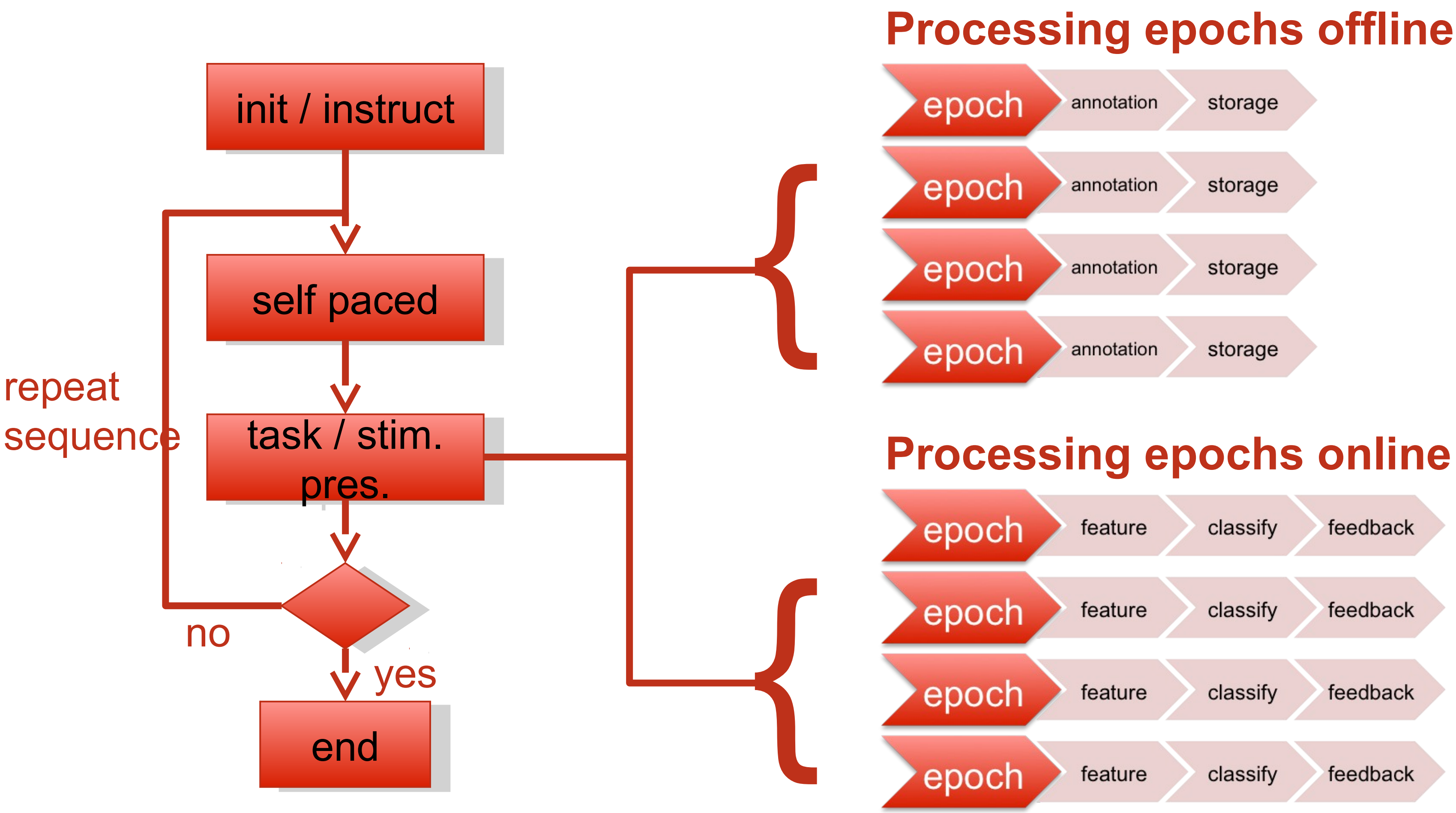


Gross structure of a typical BCI experiment

BCI terminology (our group!)

- Epoch/Trial
  - Single BCI prediction
  - e.g. 1-imagined movement, 1 visual-speller flash
- Sequence
  - Short group of epochs (~1min)
  - v. short breaks 1-2sec between epochs (usually automatic)
  - short (usually self-paced) subject break between sequences (~10sec)
- Block/Run/Phase
  - Short group of sequences (>10min)
  - long (~1-2min) subject break between blocks
  - e.g. cap-fitting, calibration, classifier training, on-line use
- Session – during one cap-fitting
- Experiment – imagined movement, visual-speller etc.

Flow chart of an individual epoch in a simple BCI experiment



Requirements: what do you need to build a BCI?

1) Way of **tracking** where we are in execution of the experiment flowchart, i.e. block, sequence, epoch number.

2) Way of **annotating** data to what the subject was experiencing/doing at that time with what was measured from their brain/body, e.g. LH movement, reading instruction, watching queue, etc.

3) **Data acquisition**: Drivers to extract data from hardware (and combine data fro different hardware sources)

4) **Stimulus Generation**: makes stimuli that the subject will experience, for subject instruction, feedback, event-related stimuli

5) Something to **process** the signals, firstly to train the classifier, and secondly to decode the users mental state, i.e. do the BCI bit ;-)

6) **Scheduler** (sequencer?) to tie it all these bits together,

- so the correct functions, i.e. stimulus display, signal processing, are executed
- at the correct position in the experiment flowchart
- based on the right bits of measured datacc

Summary

- To build a BCI we need a system to; track our progress through the experiment, acquire, annotate and process data, present the stimuli and schedule all these processes in an appropriate way.
- Next we introduce a Matlab based system which provides these facilities.

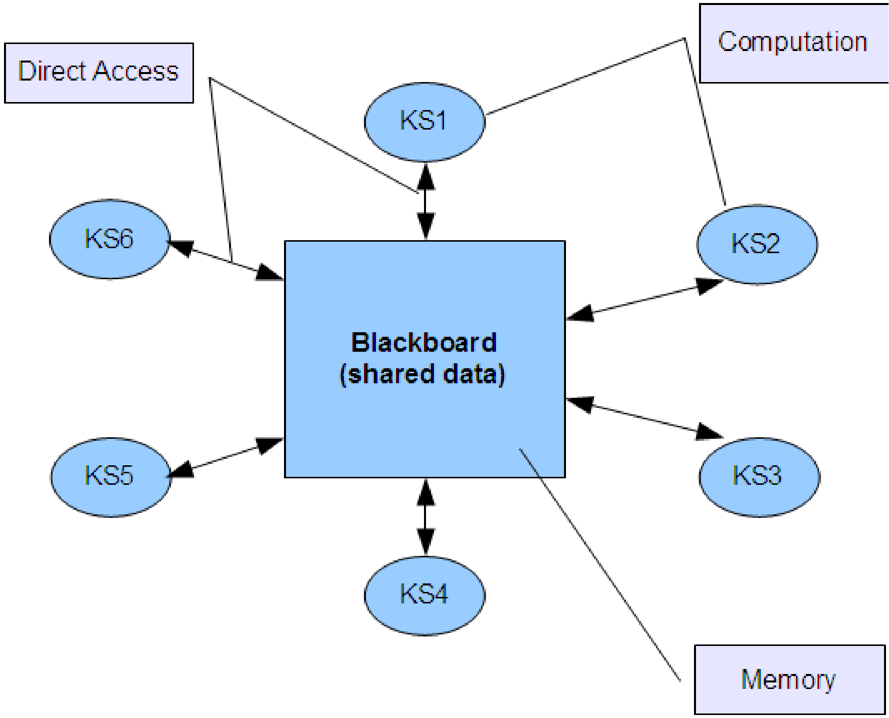
Buffer-BCI Framework

- We can break the requirements into 4 largely independent communicating processes:
  1) Data-acquisitation & annotation
     - Get data from hardware
     - Attach annotations (markers, events) to particular data sample
  2) Experiment control (scheduling)
     - Control the flow of the experiment
  3) Stimulus generation
     - Make stimuli when requested by the expt controller
     - Make feedback based on predictions generated by the sig-processor
  4) Signal Processing
     - Process the data based on the annotationss, and generate predictions

Buffer-BCI Framework

Basic Idea:

- set of independent processes
- any process can send/recieve data-annotation events
- events are visible to all other processes
- Processes communication implemented by sending recieving events
- (N.B. As all events are saved with the data, annotations are automatically archived for later off-line use).
- Similar in concept to that used in 'Blackboard architectures' for AI, see < en.wikipedia.org/wiki/Blackboard_system>



Ft-buffer based Implementation

- Buffer-BCI framework implemented using the fieldtrip-buffer system (fieldtrip.fcdonders.nl/development/realtime)
- Ft-buffer provides:
  - Drivers for data-acquisation

  1)buffer storage for data (~last 1 minute data)

  2)buffer storage for events (~last 50 events)

Idea:

- Buffer events store represents the blackboard used for inter-process communication (IPC)
- Every event has timestamp (sample number) used for data-annotation

Basic Idea:

- Client/Server architecture
- set of independent processes
- any process can send/recieve data-annotation events
- events are visible to all other processes
- Processes communication implemented by sending receiving events
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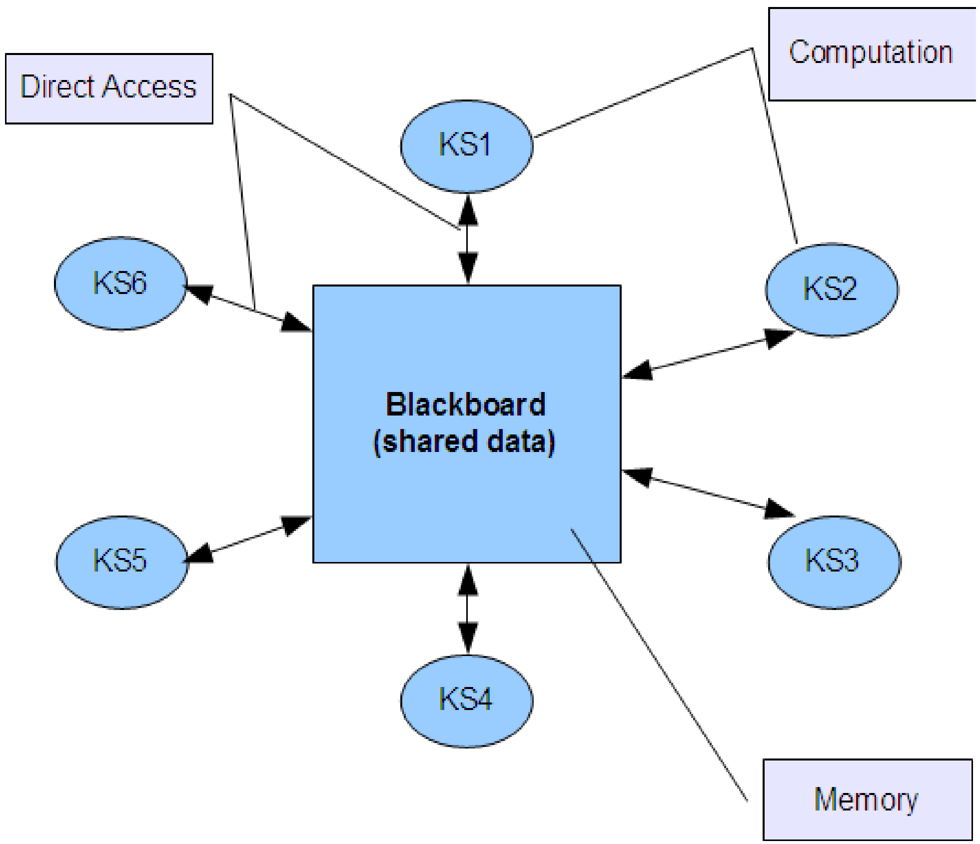

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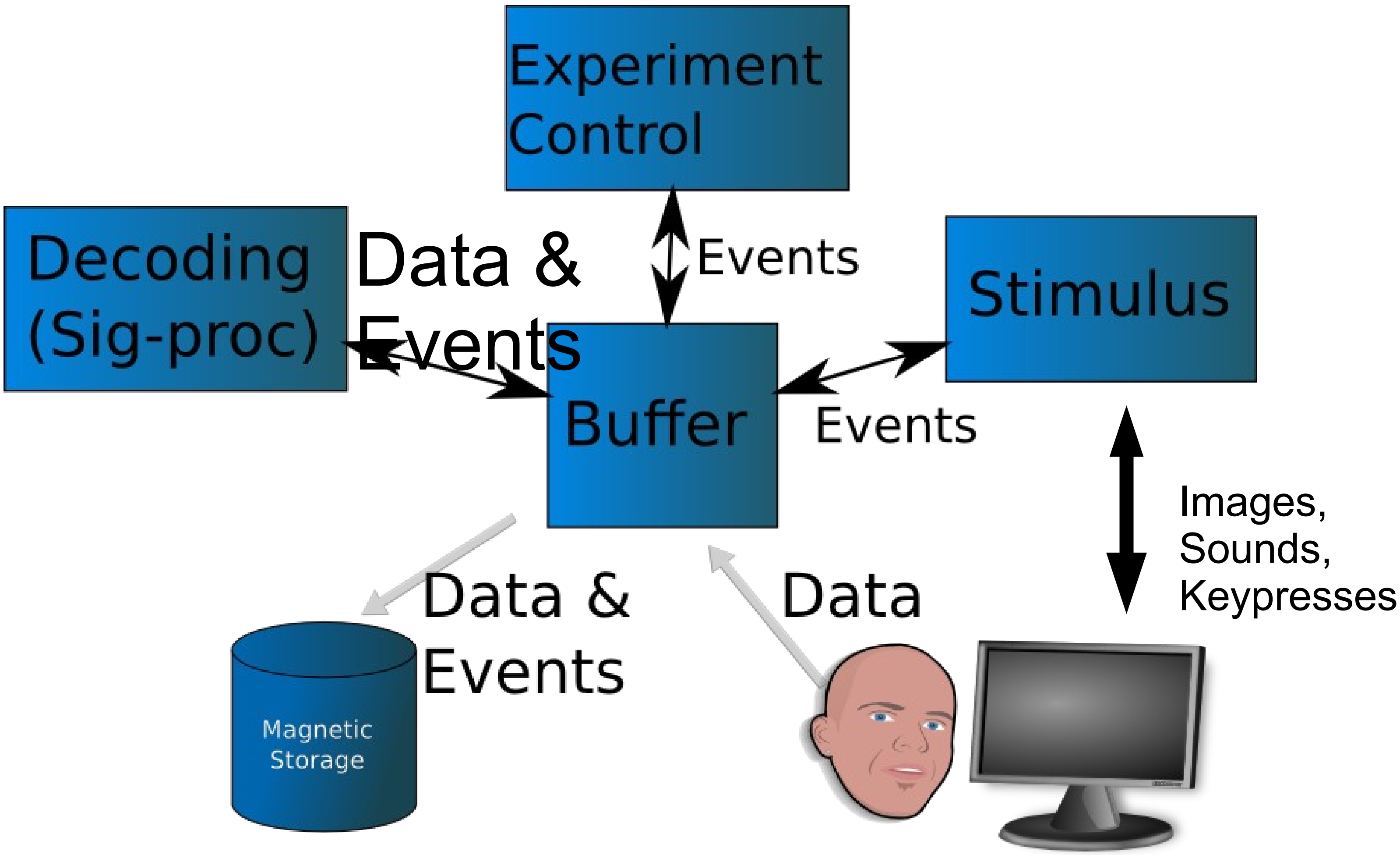
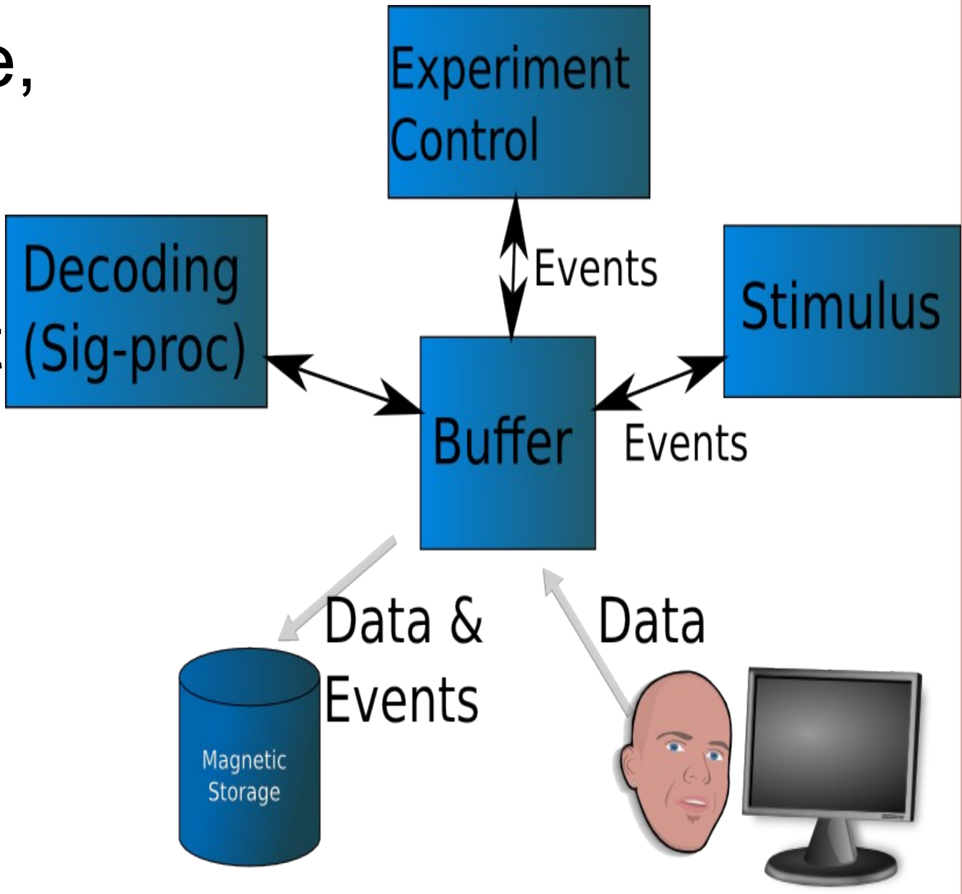
Typical Structure of BCI system



client/server architecture

1) **Buffer server**: for data storage, annotation (IPC) and archive
2) **Acquisition driver**: to access (or simulate) the measurement hardware
3) **BCI Application**.
   Normally, split into 2/3 pieces:
   1) Signal-processing
   2) Stimulus presentation
   3) Experiment control (commonly part of stimulus-presentation)



Buffer_bci Quickstart

client/server architecture

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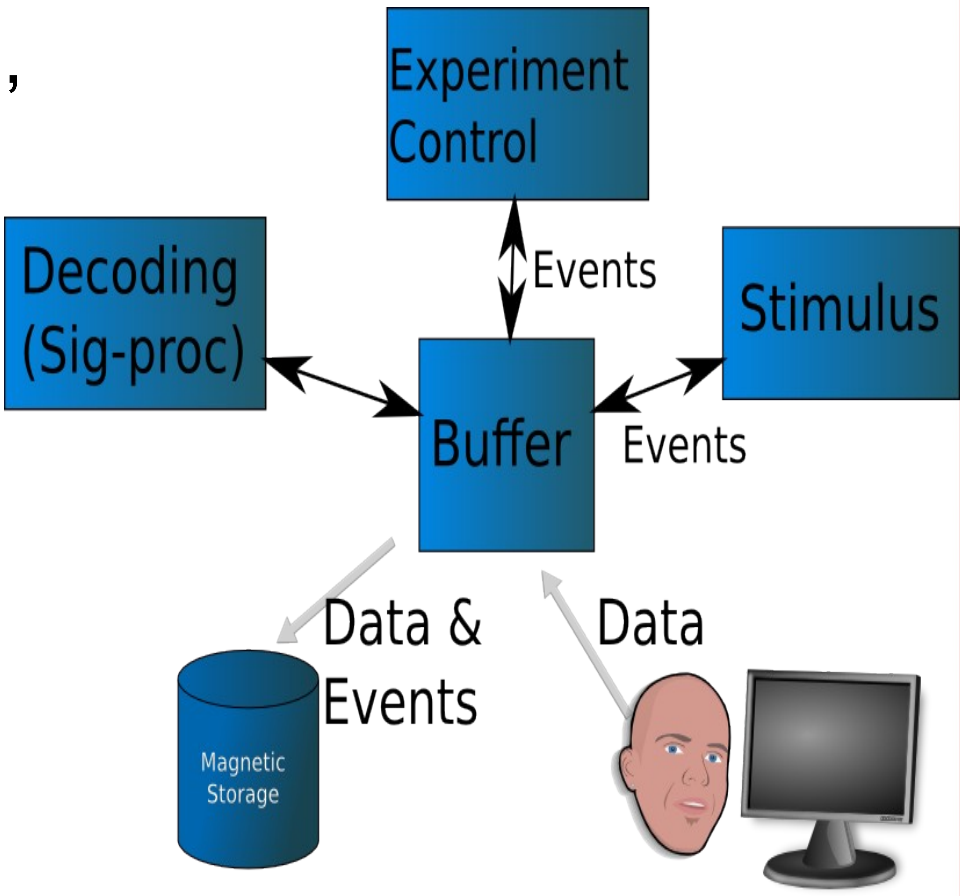


Running buffer-bci code:

You need to have (at least) the following processes running:

1) Buffer server

2) Data-acquisation system (real or simulated)

3) BCI Application

Quickstart: 1) Buffer Server

- Saving server (saves all data and events)

  `dataAcq/startJavaBuffer.{sh/bat}`

- Server (saves nothing):
  `dataAcq/startJavaNoSaveBuffer.{sh/bat}`

C-based implementations:

- Saving: `dataAcq/startBuffer.{sh/bat}`
- NoSaving: `dataAcq/startNoSaveBuffer.{sh/bat}`

Quickstart: 2) Data-acquisation

Simulated data: (for debugging/testing)

- Java-based: `dataAcq/startJavaSignalProxy.{sh/bat}`

  (Alternative implementions Matlab: `startMatlabSignalProxy`, c:`startSignalProxy`)

Real data: (for debugging/testing)

- FilePlayback: `dataAcq/startJavaFileProxy.{sh/bat}`
- Microphone: `dataAcq/startAudio.{sh/bat}`

EEG amplifier data: (for real usage)

- Biosemi: `dataAcq/startBiosemi.{sh/bat}`
- Mobita: `dataAcq/startMobita.{sh/bat}`
- OpenBCI: `dataAcq/startOpenBCI.{sh/bat}`
- Many others... (look in `dataAcq/startXXXXX.{bat/sh}`)

Quickstart: 3) BCI-Application

- Generally what you will write yourself in this course ;-)
- Typically in 2 (or more) separate processes:

1) Stimulus presentation:
   - Controls what the user sees/hears, i.e. UI
     - Show App, show feedback, control output-devices, etc.

2) Signal processing:
   - Processes the EEG data and events to generate predictions for UI feedback.
     - Collect calibration data, train classifier, generate predictions

Quickstart Example : Games-demo

1) Buffer Server:

```
dataAcq/startJavaNoSaveBuffer.{sh,bat}
```

2) Data Acquisation (simulated) :

```
dataAcq/startJavaSignalProxy.{sh,bat}
```

3) BCI Application(1) -- Stimulus Presentation:

```
games/runGame.{bat,sh}
```

4) BCI Application(2) – Signal Processing:

```
games/startSigProcBuffer.{bat,sh}
```

Useful (debugging) Functions:

- Seeing the what events are sent and when is important for debugging experiment flow.

[]=eventViewer(*host*,*port,mtype,mval*)

- Print all events matching (mtype,mval)
- (mtype,mval) are as used in matchEvents

N.B. you can run the eventViewer directly using:

```
dataAcq/startEventViewer.{bat,sh}
```

EventViewer in different languages

Basic event viewer has been implemented in multiple languages

- MATLAB: `utilities/eventViewer.m`
- JAVA : `java/echoClient/eventViewer.java`
- Python: `python/echoClient/eventViewer.py`
- C : `c/echoClient/eventViewer.c`

Hands-on 1: Event Echo-Server

Events for IPC

- As well as being used for data annotation, Events are used for inter-process-communication,
  - e.g. to communicate results from signal-processing to stimulus presentation
- To use events in this way, each process must
  - monitor for new events
  - filter out the events it should react to
  - send response events

(Key concept) event structure

sample

- time at which event occurred in samples from start of experiment

type

- arbitrary event type (usually a string)

value

- arbitrary event value (usually string or number)

duration (optional)

- duration of the event in samples

offset (optional)

- zero-time for the event.
- Usually, offset from sample at which the event actually started.

Examples:

Visual speller “flash”;

```
ev=struct('sample',123,...
          'type','stimulus.flash',...
          'value',[0 0 1 0 0],...
          'offset',0,'duration',0)
```

Classifier prediction:

```
ev=struct('sample',123,...
          'type','prediction',...
          'value',[-1 -1 -1 1 -1],...
          'offset',0,'duration',0)
```

Imagined Movement event:

```
ev=struct('sample',123,...
          'type','stimulus.move',...
          'value','left-hand',...
          'offset',0,'duration',300)
```

Compact notation:

s:123,t:'stimulus.flash',v:[0 0 1 0 0],o:0,d:0

(key functions) Event manipulation

evt=mkEvent(*type,value,[sample,offset,duration]*)

- make a buffer event, with sensible defaults

sendEvent

- *evt*=sendEvent(*type,value,[sample,offset,duration,host,port]*)
- *evt*=sendEvent(*evt*,[host,port])
- Send event to the buffer on machine host at port.

mi=matchEvents(*evts,mtype,mval*)

- Find events with type *mtype* and value *mval* in *evts* a vector of event structures.
- *mtype* – can be cell-array of types to match, e.g. {'type1' 'type2'}
- mval – can be cell-array of values to match, e.g. {'val1' 10 'val3'}
- match if any *mtype* matches and any *mval* matches,
    - i.e. above matches (t:'type1',v:10), (t:'type2',v:10),(t:'type1',v:'val1')
- mi is logical vector of which evts matched
- N.B. Empty ([]) or '*' mtype/mvalue matches everything

Hands-on 1: Event Echo-Server

Experiment Task

- Write a simple echo-server which:
  - Connects to the Buffer server
  - Waits for **any** incomming event, and
  - Responds by sending a 'echo' event with the same value but type='echo'
  - Quits if it recieves and event with type='exit'
- N.B. Don't 'echo' your own echo events!

Assignment:

- start from : `echoServer_skel.m`

N.B. send 'keyboard' events by pressing keys in the signal proxy window.

Useful Functions:

- Setup MATLAB paths and connect to buffer:
  - See the header code block in echoServer_skel.m
  - This will initialize the paths:

    ```
    run ../../utilities/initPaths.m
    ```

  - Then try to connect to the buffer server until valid header is returned.

    ```
    while ( isempty(hdr) ||.....
    ```

  - Then initialize some utility functions for high-precision timing

    ```
    initsleepSec();initgetwTime();
    ```

Useful Functions:

[devents,state]=...

buffer_newevents(*host*,*port*,*state,mtype,mval,timeout_ms*)

- wait for any new events matching (*mtype,mval*)
  - Matching done by *matchEvents*

    mtype – can be cell-array of types to match, e.g. {'type1' 'type2'}

    mval – can be cell-array of values to match, e.g. {'val1' 10 'val3'}

    match if **any** mtype matches **and any mval** matches
- return the matched events in the vector of structure(s) *devents*
- *state* is the match state, used to track which events have been processed between function calls
- Return after timeout_ms milliseconds even if no matching events found

Debug/Test your echoSever

- Start an event viewer: `dataAcq/startJavaEventViewer.{sh,bat}`
- Generate events to be echo'ed:
  - Directly from Matlab:
    - Start 2nd Matlab
    - Connect to buffer
    - Send events: `sendEvent('type','value')`
  - OR:

    From the signal-proxy:
    - Start the Matlab signal proxy:

      `dataAcq/startMatlabSignalProxy.{sh,bat}`
    - Press keys in the SignalProxy window to generate {t:keyboard, v:key} events

Echo-Server in different languages

Basic echo-server example has been implemented in multiple languages

- MATLAB: `echoClient/matlabclient.m`
- JAVA : `java/echoClient/javaclient.java`
- C# : `csharp/echoClient/csharpclient.cs`
- Python: `python/echoClient/pythonclient.py`
- C : `c/echoClient/cclient.c`

Hands-on 2: “Hello World”

Experiment Task

- Display the string “Hello World” (or any other pre-specified string) on the screen, and wait for a key to be pressed to exit
- Send events to annotate what has happened, e.g. startup, string display, key-pressed, shutdown etc.

Method:

- Start from the 'helloworld_skel.m' function skeleton
  - contains initialisation code to connect to the ft_buffer
  - Some examples of functions you may find useful

Note : event timestamps

- Accurate event time-stamps are critical for evoked potential analysis
  - >10ms event jitter causes significant reduction in signal quality
- However,
  - data-acquisation may only send data every >20ms
  - And this data may be subject to additional network delays of >20ms
- Stop this jitter reducing time-stamp accuracy by;
  - aligning (and tracking) computers real-time-clock and data-sample clock to prevent this jitter reducing time-stamp accuracy

Hands-on 3: Sequenced Sentences

Experiment Task

- display set of sentences on the screen where every second 1 more character gets added to the sentence
- pause for 5 seconds between sentences (and/or wait for key press)
- send events for everything that happens

Assignment:

- Make flowchart
- Write code -> test -> debug -> until it works :-)
- Start from runSentences_skel.m

Useful Functions:

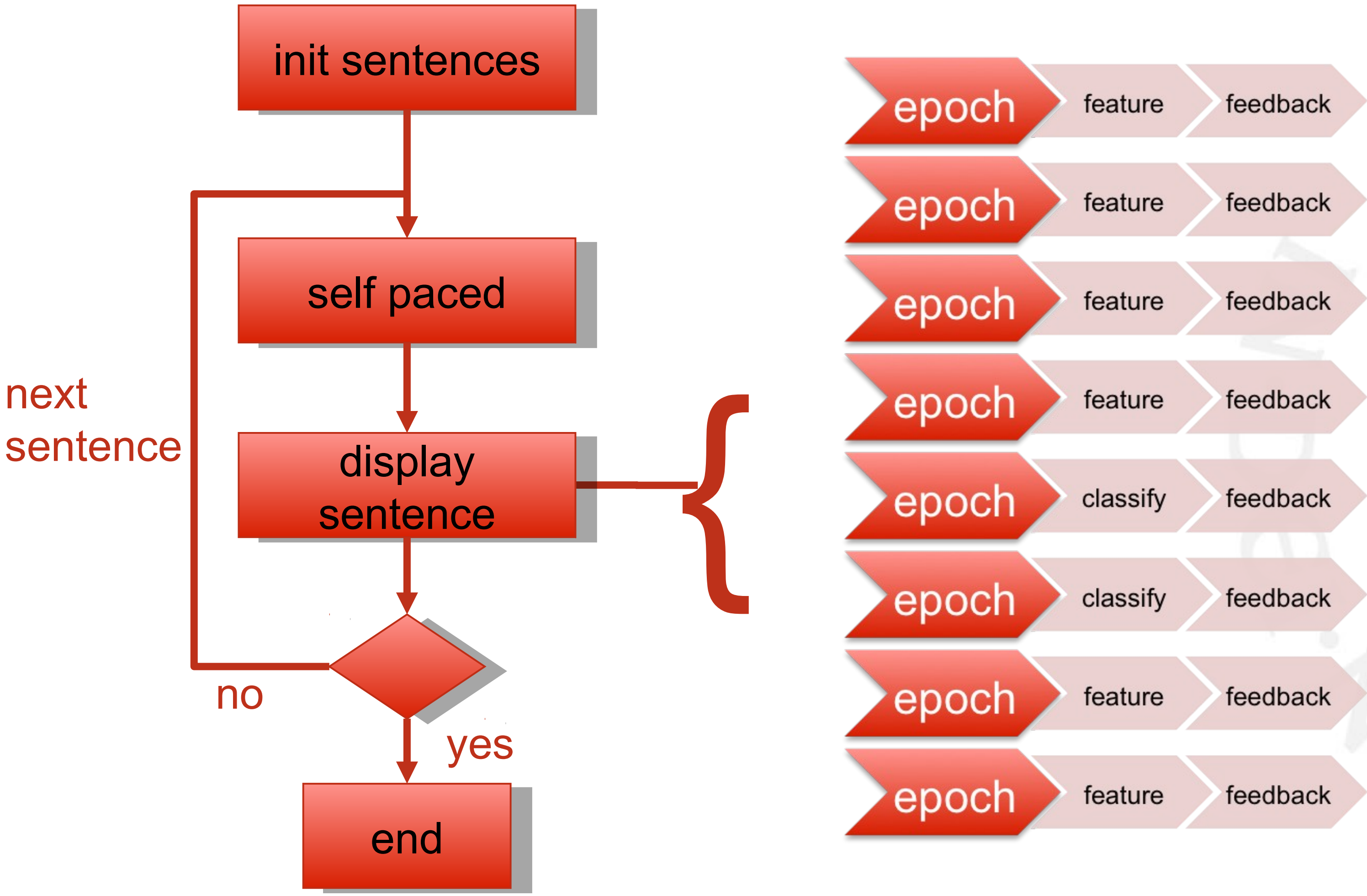
- sleepSec(time)
  - cause matlab to sleep for the indicated duration in seconds (more accurate than 'pause').

Flowchart : sequenced sentences

sequenced sentence

Sentence

Stimulus presentation



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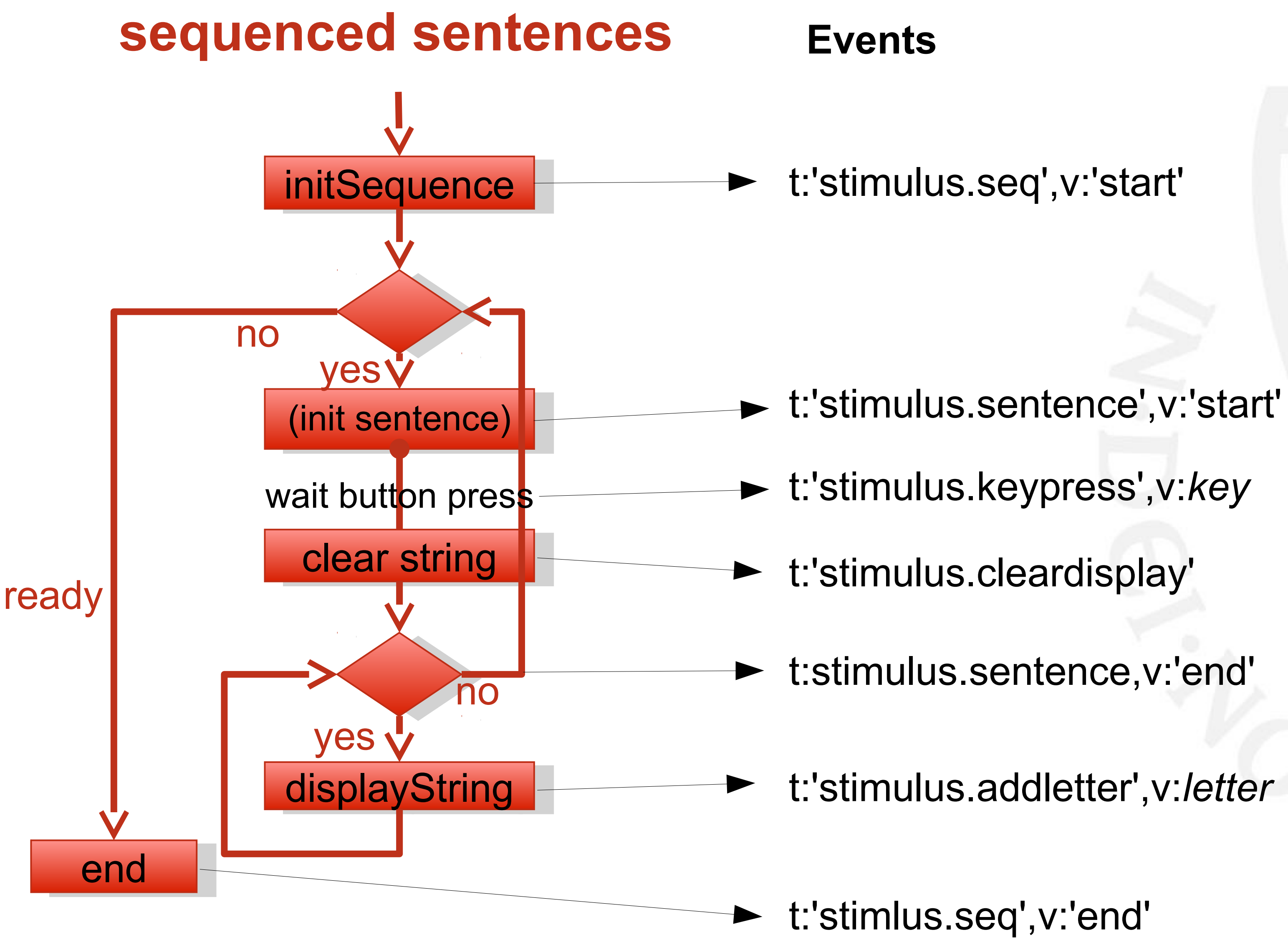
end of sequence

Events and processing functions



Hands-on 4: ERP Viewer

Experiment Task

- In 5 sequences of 10 seconds:
  - Every 1 seconds: either randomly display or don't display a cross (+) on the screen for 200ms
- Display a 'Press key to continue string' between sequences, and wait for key press to move to the next sequence
- For every 'stimulus event', i.e. point when the '+' could have been displayed, record 600ms of data annotated with whether it was a '+' or not
- Every time you get some data, compute an average of the EEG data for that type of stimulus, i.e. + or no-+, and display the resulting averages as a multi-plot on the screen

- N.B. You will need a separate signal processing process to: get the data, compute the ERP and display the results!

Assignment:

- Make flowchart for each of the processes, i.e. stimulus, and signalProcessing
- For the expt-control & simulus presentation start from : runStimulus-skel.m
- For the signalProcessing & results genration use : runSigProc-skel.m

Useful Functions:

[data,devents,state]=buffer_waitData(*host*,*port*,*state*,...

'startSet',*startEvts*,'trlen_samp',*samp*,'exitSet',*exitEvts*)

- for all events matching *startEvts* record *samp* samples of data
- until an event matching *exitEvts* is generated
- *startEvts* and *exitEvts* specify the events to match in the format:
  - type – event type has this value
  - {'type' val} – event has type==type and value==val
  - {{'type1' ''type2'}} – event has type == 'type1' or 'type2'
  - {{'type1' 'type2'} {val1 val2}} – event has type == 'type1' or 'type2' **and** value== val1 or val12
- return the matched event structure(s) in *devents* and corrospending data in *data*
  - *Data* is a vector of structures. data.buf = [nChannels x nSamples] raw EEG data
- *state* is the match state, used to identify which events have been processed between function calls

- N.B. *ExitEvts* has the special event type 'data' which returns as soon as the data is available for the first matched *startEvt*

Summary

- BCI can be broken into 4 processes: data-acquisation, experimental control, signal processing, and stimulus presentation
- buffer_bci framework : uses buffer events as a blackboard for inter-process communication