Modeling Actuations in BCI-O: A Context-based Integration of SOSA and IoT-O

https://w3id.org/BCI-ontology#

Semantic Models for BCI Data Analytics

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2018.10.15

- BCI: Brain-Computer Interface
- BCI Ontology: Origins & Motivation
- BCI Ontology: Overview
- BCI Ontology: Actuation Model
- BCI Ontology: Use Case Modeling
- Final Remarks

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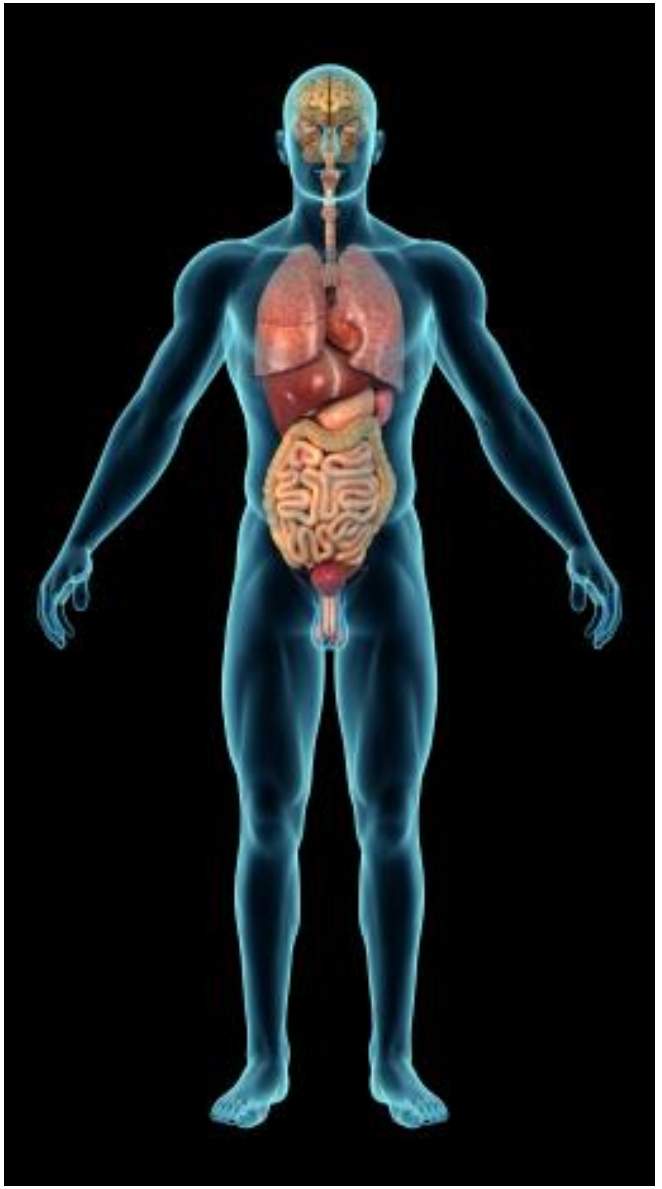
- Brain-Computer Interface (BCI)
- EEG: Basic Operations
- BCI System: Basic Components
- EEG (Electroencephalogram)
- EEG Signals
- Metadata in BCI

Just a quick overview…

BCI: BRAIN-COMPUTER INTERFACE

The Human Body

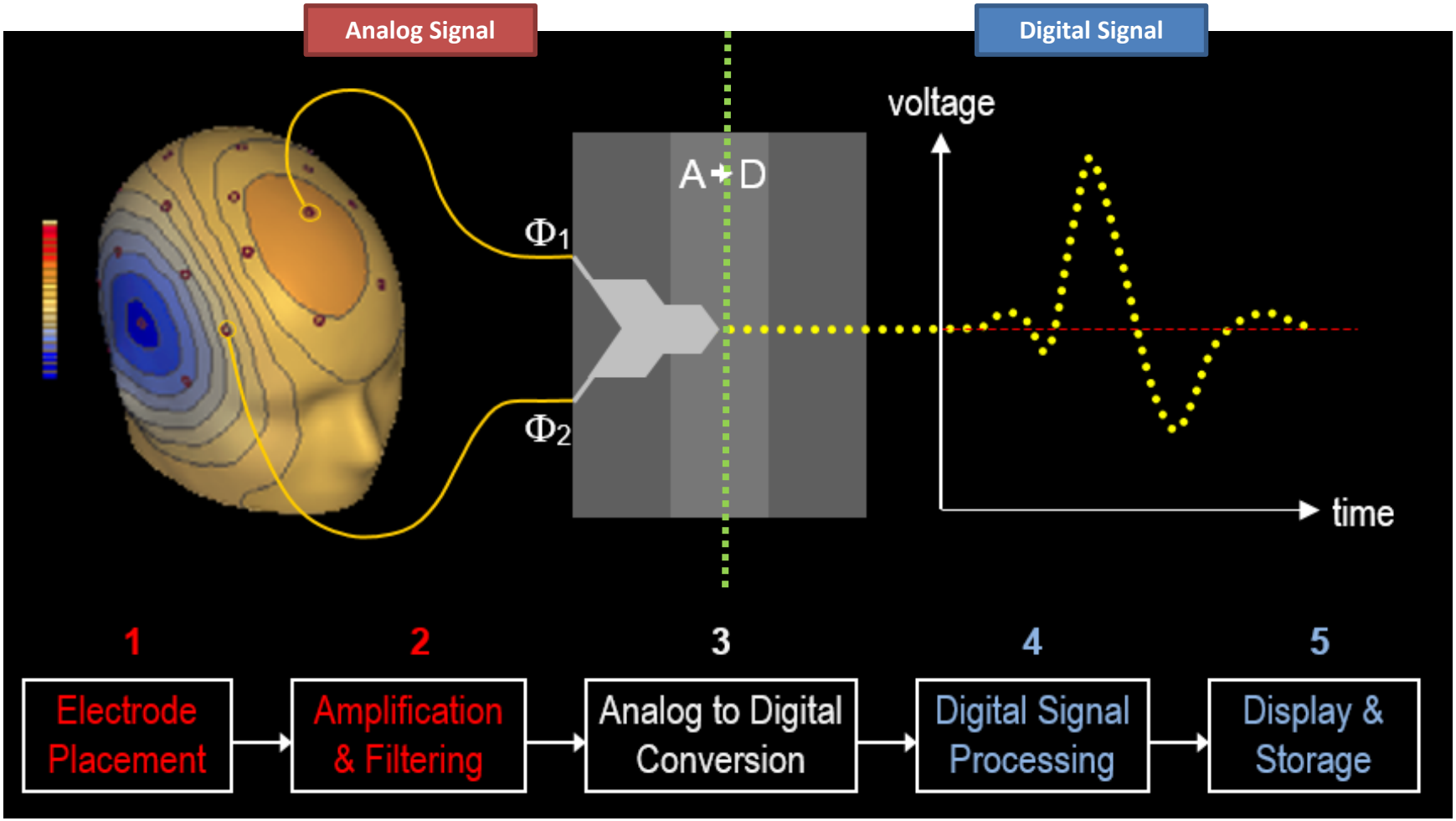
- A biological machine composed of different systems (mechanical, chemical, etc.)
- Components: organs.
  - ❖ Lungs.
  - ❖ Liver.
  - ❖ Heart.
  - ❖ Brain.



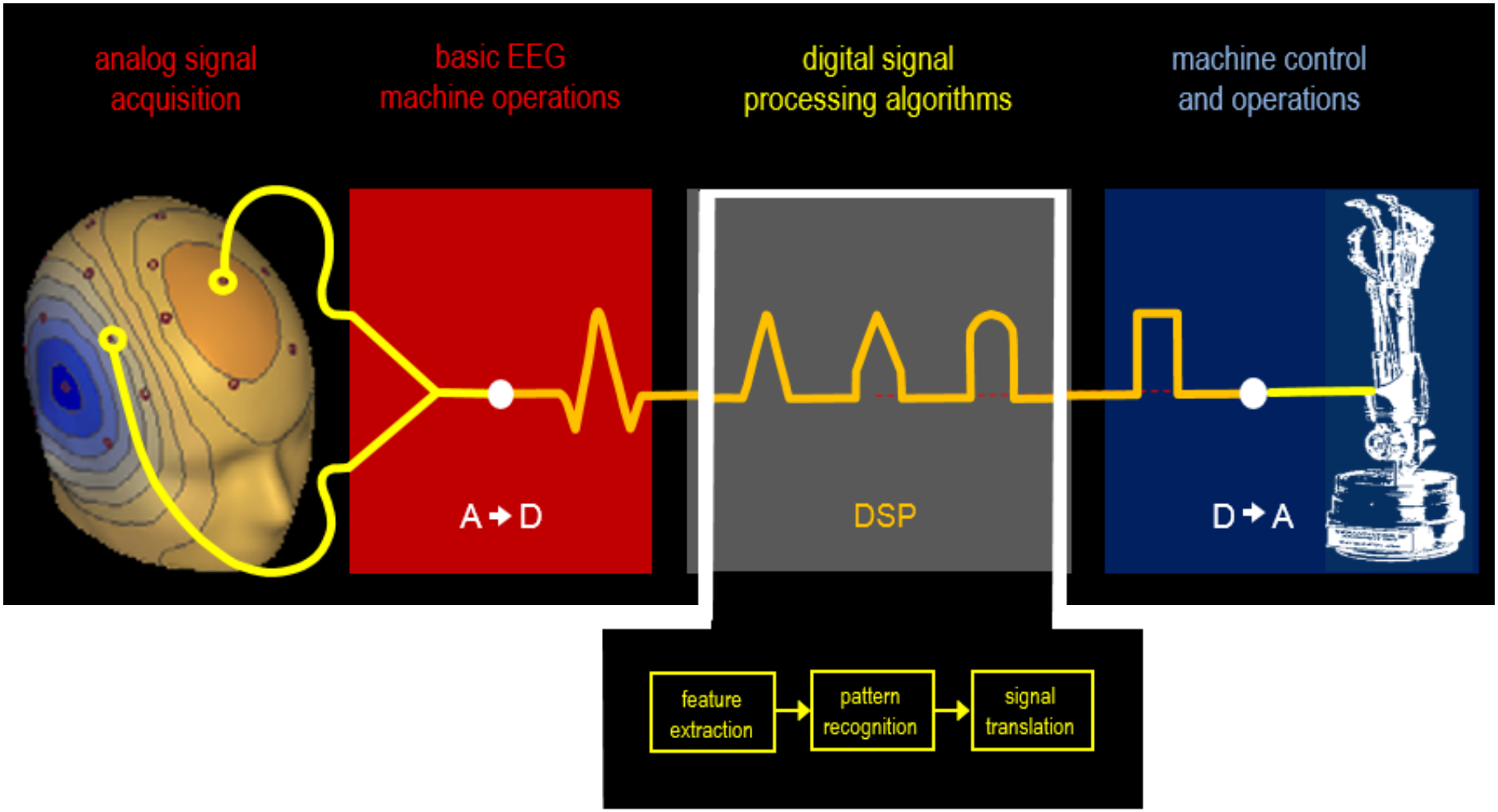
Brain-Computer Interface (BCI)

- A computer-based technology that allows the brain to communicate with external devices in order to restore, assist, or augment cognitive, sensory, and/or motor functions.
- BCI research began in the 1970s under a grant from the NSF followed by a contract from DARPA.
- BCI research was initially conducted on animals.
- The first BCI prosthetic device was implanted in humans in the mid-1990s.
- EEG-based BCI is the most studied and perhaps the most clinically promising BCI technology
  - non-invasive, superior temporal resolution, ease of use, portability, and low set-up cost

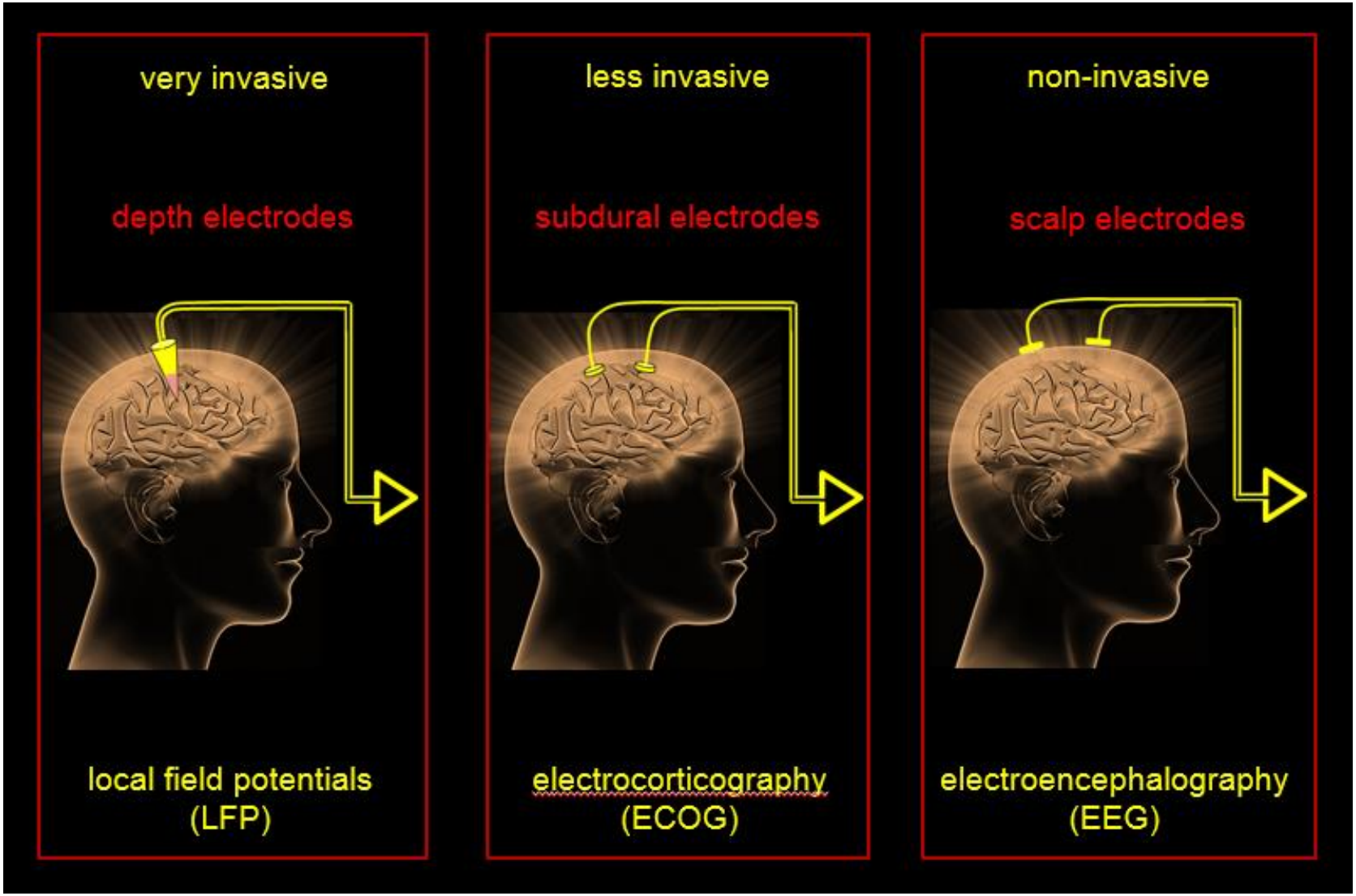
EEG: Basic Operations



BCI System: Basic Components

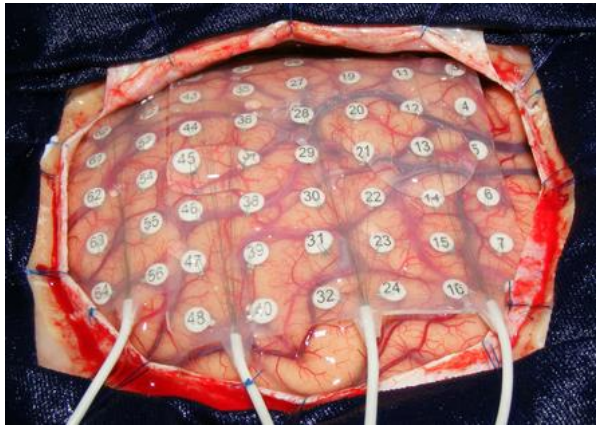


BCI Evolution



EEG (Electroencephalogram)

- It is a recording of the electrical activity of the brain from the scalp.
- 2 general methods to measure
  - Invasive:
    - Requires operation to remove scalp and place electrode directly on the surface of brain.
    - Very clean EEG signals.
  - Non-invasive:
    - Electrodes are placed on scalp.
    - Noisy EEG signals (artifacts)



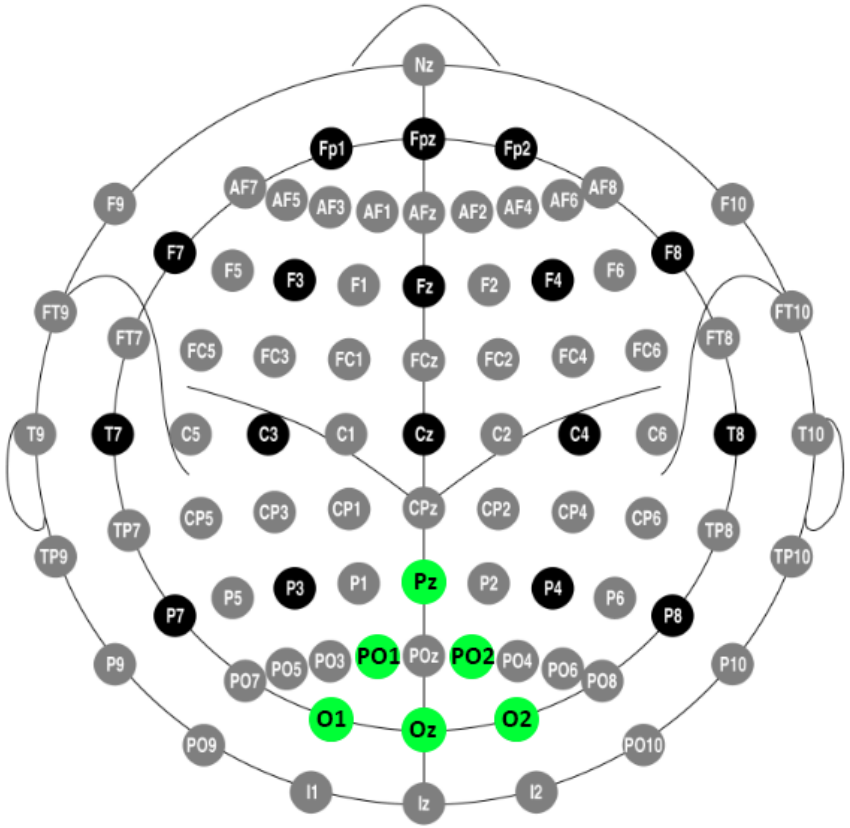
EEG (Non-Invasive): Sensors Evolution

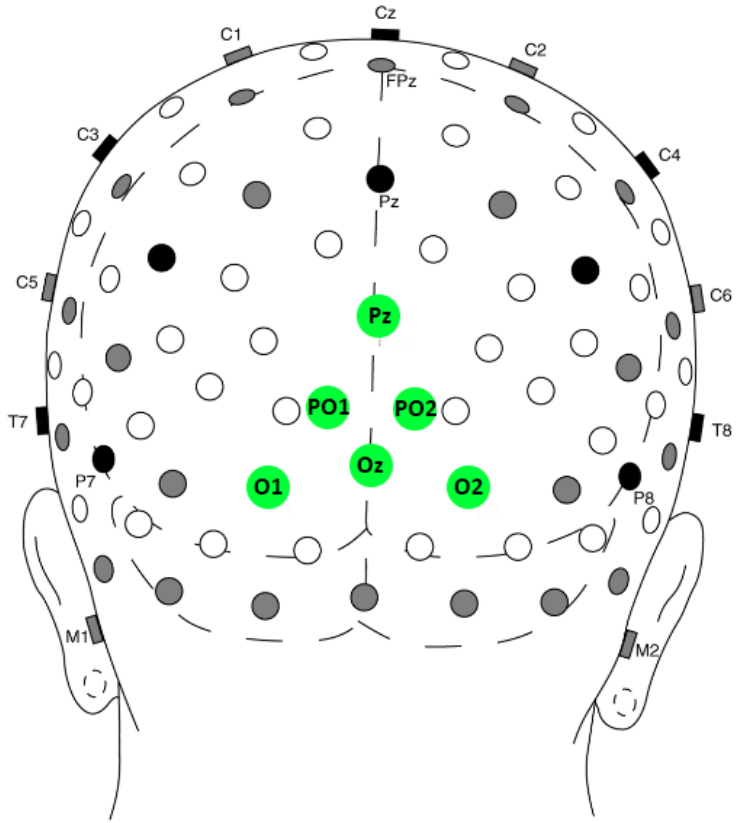
- Wet Electrodes
- Not portable
- Expensive and complicated setup

- Dry Electrodes
- Portable
- Moderate cost and easy to setup

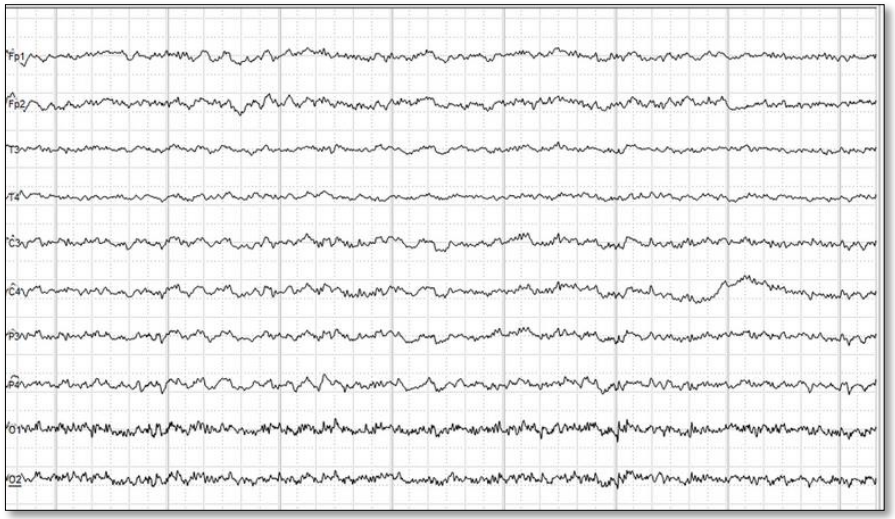
EEG Channels (10-20 EEG System)

- ***Green*** *electrodes denotes the EEG channels used for experiment*
- ** Parietal (P), Occipital (O) are the channels that shows strongest EEG response when presented with a visual stimuli*



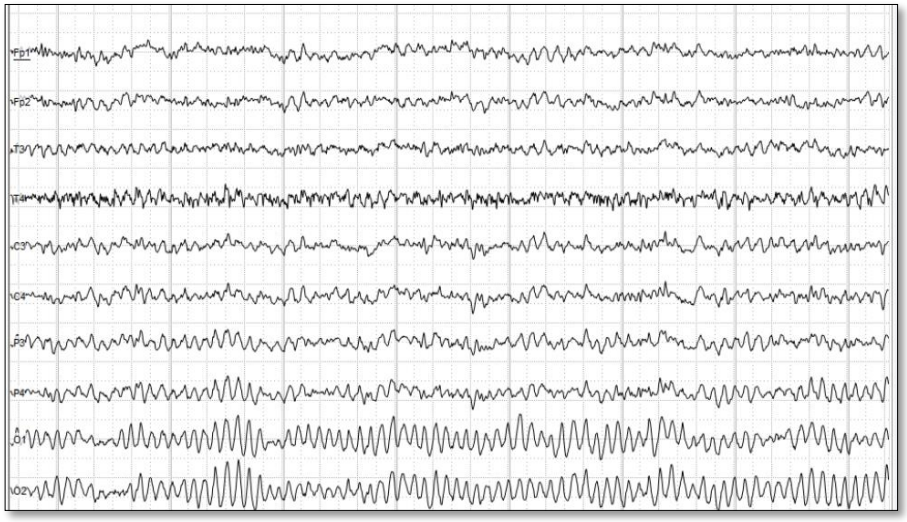


EEG Signals



Resting State

E.g. open eyes, relaxed

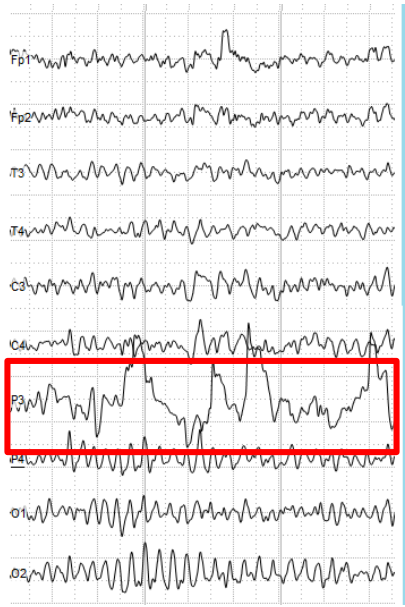


Alpha State

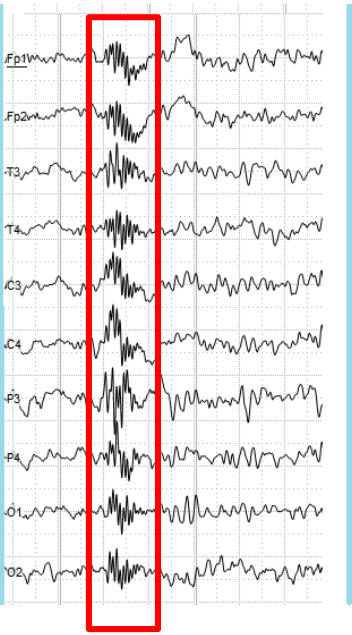
E.g. close eyes

EEG Signals: Artifacts

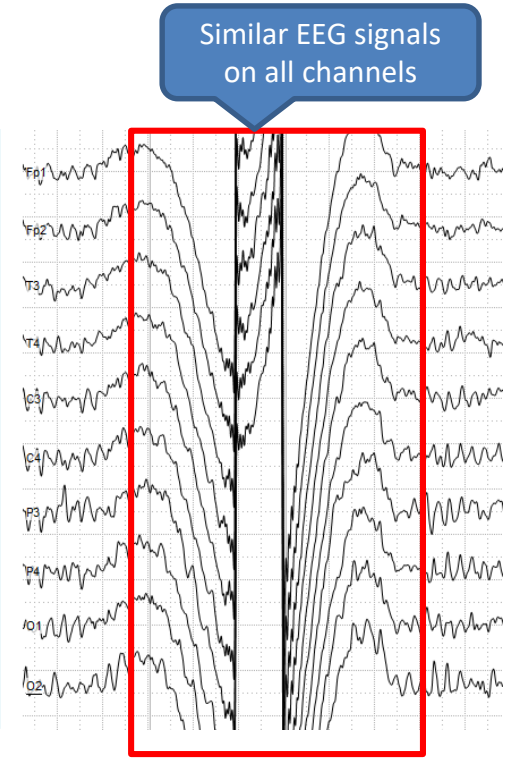
Artifact 1:
Eyeball muscle (blinking)



Artifact 2:
Poor electrode contact



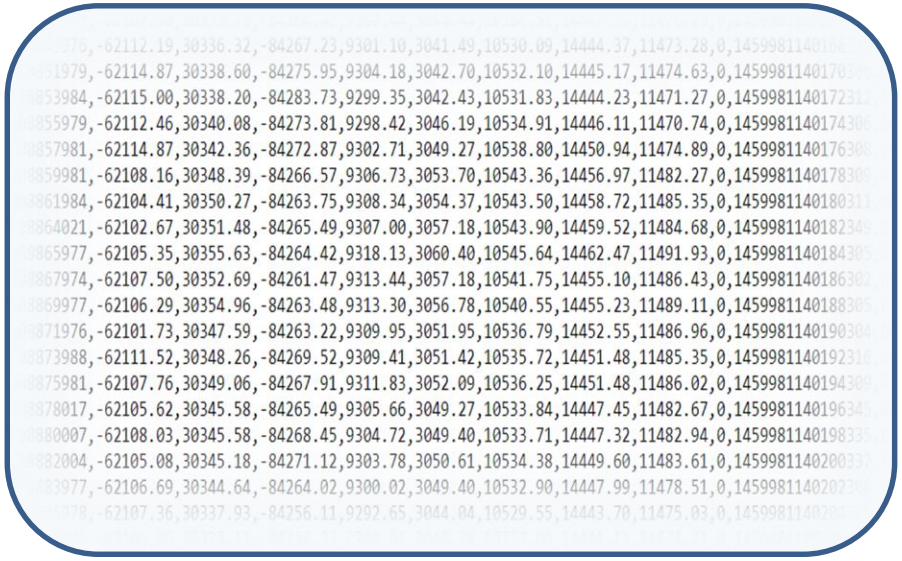
Artifact 3:
Swallowing



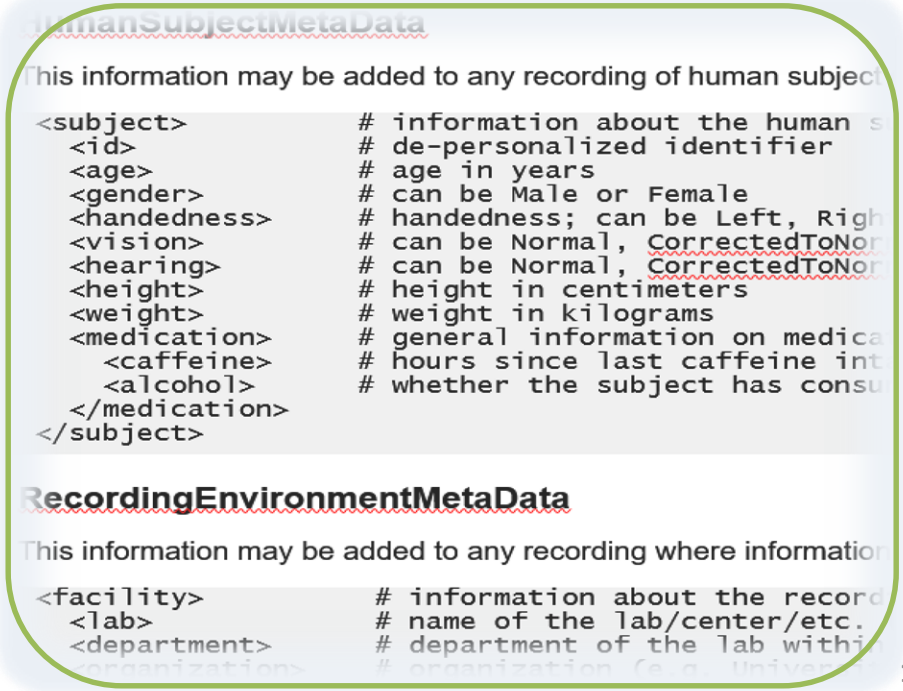
Artifact 4:
Poor electrode contact (Reference channel and skin)

Metadata in BCI

- Raw bio-medical signals:
  - different human activity measurement levels over time
  - Heterogeneous / multimodality



- Metadata
  - Identify relevant characteristics
  - Descriptive set of annotations/tags/attributes.
  - Purpose: **classification (**raw data and models about them**)**



Metadata in BCI

xdf

XDF (Extensible Data Format)

XDF (Extensible Data Format) is a general-purpose container format for multi-channel time series data with extensive associated meta-information. XDF is tailored towards bio-signal data such as EEG, EMG, EOG, ECG, GSR, MEG, etc., but can easily hold data with high sampling rate (like audio) or high numbers of channels (like fMRI or raw video), as well. Meta-information is stored as XML.

XDF is open source and designed to be a community project; that is, everyone is invited to contribute to the format specification. The core specification of the format is kept as simple as possible, but at the same time rich enough to support features such as time stamp corrections, boundary chunks for seeking, and data streams supporting many different data types (including int, float, double, string).

Introduction

HumanSubjectMetaData

This information may be added to any recording of human subject data.

```
<subject>          # information about the human subject
  <id>             # de-personalized identifier
  <age>            # age in years
  <gender>         # can be Male or Female
  <handedness>     # handedness; can be Left, Right, or Equal
  <vision>         # can be Normal, CorrectedToNormal, Impaired
  <hearing>        # can be Normal, CorrectedToNormal, Impaired
  <height>         # height in centimeters
  <weight>         # weight in kilograms
  <medication>     # general information on medication and other sub-
stance effects
    <caffeine>     # hours since last caffeine intake, if less than 12
hours
    <alcohol>      # whether the subject has consumed alcohol within 24
hours before the recording (Yes or No)
  </medication>
</subject>
```

EEGMetaData

If a stream has the content-type EEG, we recommend that meta-data about the stream adheres to the structure and naming laid out in the following. While all meta-data is optional, we recommend that any stream should describe at least the channel labels.

```
  <channels>           <!-- per-channel meta-data; might be repeated -->
   <channel>           <!-- description of one channel, repeated (one
for each channel in the time series) -->
    <unit>             <!-- measurement unit (strongly preferred unit:
microvolts) -->
    <type>             <!-- channel content-type (EEG, EMG, EOG, ...) --
>
    <label>            <!-- channel label, according to labeling scheme;
                            the preferred labeling scheme for EEG is 10-
20 (or the finer-grained 10-5) -->
    <location>         <!-- measured location (note: this may be arbi-
trary but should then include
                            well-known fiducials (landmarks) for co-reg-
istration) -->
      <X>              <!-- coordinate axis pointing from the center of
the head to the right, in millimeters -->
      <Y>              <!-- coordinate axis pointing from the center of
the head to the front, in millimeters -->
      <Z>              <!-- coordinate axis pointing from the center of
```

ExperimentMetaData

This page specifies the meta-data for the experiment.

```
<experiment>       # information about the experiment
  <id>             # experiment identifier

 <session>         # information about the experiment session
   <id>            # session identifier or sequence number
   <permutation>   # permutation code, if any
   <pilot>         # whether this is a pilot session (Yes/No)
   <role>          # role of the session in the experiment (e.g.,
training, baseline)
  </session>

 <task>            # information about the experimental task, if any
   <label>         # label of the task (e.g. Flanker)
   <description>   # verbal task description
   <citation>      # citation for the task design
  </task>

 <script>          # information about the experiment script
   <location>      # external location of the experiment script
   <code>          # actual code of the script, if available
   <language>      # language that the script was written in (e.g., P
```

Metadata in BCI

EEG Study Schema 2.0

Folder/File Structure and Naming Convention

Definition of terms:

- **Study**: A set of data collection efforts to answer one or few related scientific questions.
- **Study Label**: a short (10 characters or less) label to be used in naming files associated with the study.
- **Task**: Each study may contain multiple tasks. For example a baseline 'eyes closed' task, followed by a 'target detection' task and a 'mind wandering', eyes open, task. Each task contains a single paradigm and in combination they allow answering scientific questions investigated in the study. ESS allows for event codes to have different meanings in each task, although such event encoding is discouraged due to potential for experimenter confusion.
- **Task Label**: A short (10 characters or less) label for each task in the study.

XML (study_description.xml)

The left side (in bold) is the ESS XML tree structure. On the right side of the document, is a short description of the specified node and a short explanation of what should be written within the node. The words 'tag' and 'node' are used interchangeably in this this document.

Use NA or dash (-) for specifying 'not available'. Empty spaces are assumed to be data that has not been entered yet.

<?xml version="1.0" encoding="UTF-8">	: information about XML encoding used. Do not modify.
<?xml-stylesheet type="text/xsl" href="xml_style.xsl"?>	: path to the styling document. This allows conversion to human-readable reports in modern browsers. The file xml_style.xsl should be always be placed in the sme folder. Mandatory.
<study>	: marks the beginning of the xml schema for a specific experimental study
<essVersion><essVersion>	: version of ESS used (here 2.0). This tag is mandatory for ESS versions 2 and above. (if not present, ESS version is assumed to be 1.0).
<title></title>	: the title of the study
<shortDescription></shortDescription>	: a short (less than 120 characters) description of the study (e.g. explanation of study goals, experimental procedures utilized, etc.)
<description></description>	: a detailed description the study (e.g. explanation of study goals, experimental procedures utilized, etc.)
<uuid><uuid>	: a unique identifier (uuid) with 32 random alphanumeric characters and four hyphens). It is used to uniquely identify each ESS document.

<sessions>	: information about multiple sessions
<session>	: information about individual session
<number></number>	: number identifies individual session (e.g. 1, 2, ..)
<taskLabel></taskLabel>	: indicates which task is being performed in the session (e.g. A, B, C,...) Only use this node if there are different tasks. Otherwise leave the node blank. If different tasks occur in the same session repeat the session node with a different taskLabel, and other information that may be different, such as the dataRecording node.
<purpose></purpose>	: purpose of holding session (e.g. training, testing, etc.)
<labId></labId>	: identifier of session used in original lab notes (if available, otherwise insert 'NA')
<subject>	: information about subject
<labId></labId>	: de-personalized subject identifier (if available, otherwise insert 'NA')
<inSessionNumber> </inSessionNumber>	: Each study may have multiple subjects. These subjects may or may not have labIds but they are numbered for the sole purpose of distinction, arbitrarily and in the context of the session. For example session 1 will have subjects with inSession numbers 1 and 2 , while session 2 may also have subjects with InSession numbers 1 and 2 but they may refer to two other subjects. This numbering is only to allow association between files and subjects in potential absence of subject labIds.
<group></group>	: type of subject group the subject belongs to (e.g. autistic, normal, control...)
<gender></gender>	: subject's gender
<YOB></YOB>	: subject's year of birth only
<age></age>	: subject's age (in years) at the time of recording.
<hand></hand>	: subject's dominantly used hand (R: right,L: left, or A-ambidextrous)
<vision></vision>	:can be Normal, CorrectedToNormal, Impaired

- ✓ BCI: Brain-Computer Interface
- ❑ BCI Ontology: Origins & Motivation
- ❖ BCI Ontology: Overview
- ❖ BCI Ontology: Actuation Model
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- ❖ Final Remarks

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- ➢ The Research Project
- ➢ "Augmented" Brain-Computer Interaction (A-BCI)
- ➢ Issues
- ➢ Research Description

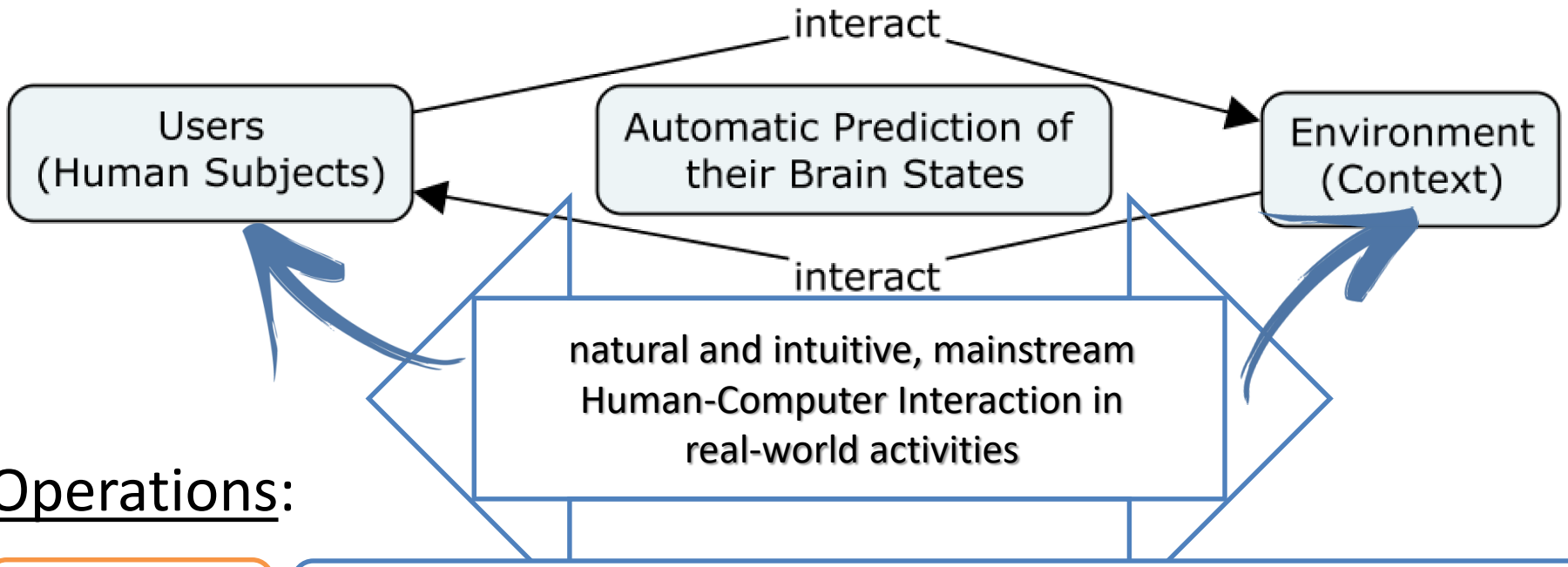
A mechanism to query and discover similarities among the BCI Metadata?

BCI ONTOLOGY: ORIGINS & MOTIVATION

The Research Project

- Research area: *Advanced Computational Approaches*.
- Program: the *Cognition and Neuroergonomics Collaborative Technology Alliance* (CaN-CTA).
- Sponsorship: the *U.S. Army Research Laboratory* (ARL).
- Participants:
  - Pervasive Embedding Technologies (PET) Lab, National Chiao Tung University (NCTU), Taiwan.
  - Swartz Center for Computational Neuroscience (SCCN), University of California in San Diego (UCSD).
- Goal: to develop a semantic model that can aid…
  - the search for correlated neuro-physiological features for characterizing individual's cognitive states including fatigue, vigilance and enlightenment.
  - the gathering of useful data sets for conducting interpersonal *Transfer Learning*.

“Augmented” Brain-Computer Interaction (A-BCI)



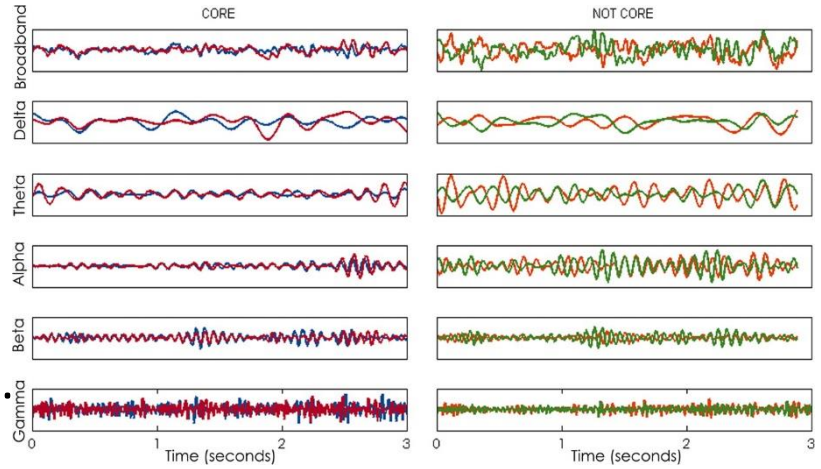
Operations:

+ [**Data**]	collect vast amounts of real-world multimodal (EEG) and activity data
+ [**Metadata**]	annotation with metadata specifying relevant situations and events
+ [**Search**]	for **similar** data sets
= [**To aid**]	machine learning in producing accurate brain state classification models

Issues

- **Costly — labor-intensive and time-consuming**, to collect a significant amount of raw data from each human subject (individual) to generate BCI informative training data.
  - Hinders the applications of BCIs in real-world settings.

- **Substantial inter-subject variability** of human raw data could deteriorate more than improve the BCI performance.
  - A reliable mechanism to identify and select (query) similar raw data sets is needed based on the available **metadata**.




```
<recordingParameterSet>
  <recordingParameterSetLabel>rset_1</recordingParameterSetLabel>
  <channelType>
    <modality>
      <type>EEG</type>
      <samplingRate>1024</samplingRate>
      <name>Biosemi</name>  <!- - Brand of the sensor device - ->
      <description/>
      <startChannel>1</startChannel>
      <endChannel>68</endChannel>
      <subjectInSessionNumber>1</subjectInSessionNumber>
      <referenceLocation>CMS</referenceLocation>
      <referenceLabel>CMS</referenceLabel>
      <channelLocationType>10-20</channelLocationType>
      <channelLabel>Fp1, AF7, AF3, F1, F3,...,</channelLabel>
      <nonScalpChannelLabel>VEOG1, VEOG2, HEOG1, HEOG2
      </nonScalpChannelLabel>
    </modality>
  </channelType>
</recordingParameterSet>
```

- **Metadata formats**. Stored in non-structured and semi-structured proprietary file formats. Not interoperable.
- **No formal structure for the metadata**. BCI metadata lacks a formal and organized structure to capture the data features (concepts and relationships).
- **No easy way to perform metadata retrieval tasks**: No queries and look for hidden patterns (discovery of relationships).

Research Description

Proposal	A semantic-based approach for BCI metadata allows identifying similar raw data sets through queries and discovery constructs among the metadata structured on an OWL 2 ontology
Deliverable	An OWL 2 ontology to organize the BCI metadata ❑ Based on Design Patterns; aligned to upper/standard ontologies for sensors/actuators. ❑ Integration of models: reconcile concepts and alignments for interoperability. ❑ Context Model: a novel model to capture the architectural features of any environment.
Goal	Use a *semantic overlay* as a means to look for **relevant** sets (*similarity and inferencing*) among BCI metadata
Main Contribution	An axiomatization to capture relevant descriptive and predictive features of the multimodal data
Exploration	Semantic search and inference rules to discover implicit metadata patterns
Purpose	To aid/ease the tasks that perform brain state predictions (classification of brain states analysis) — special interest in feature-based Transfer Learning
Vision	Assist A-BCI to build profiles and trends of brain dynamics in diverse real-life activities/circumstances

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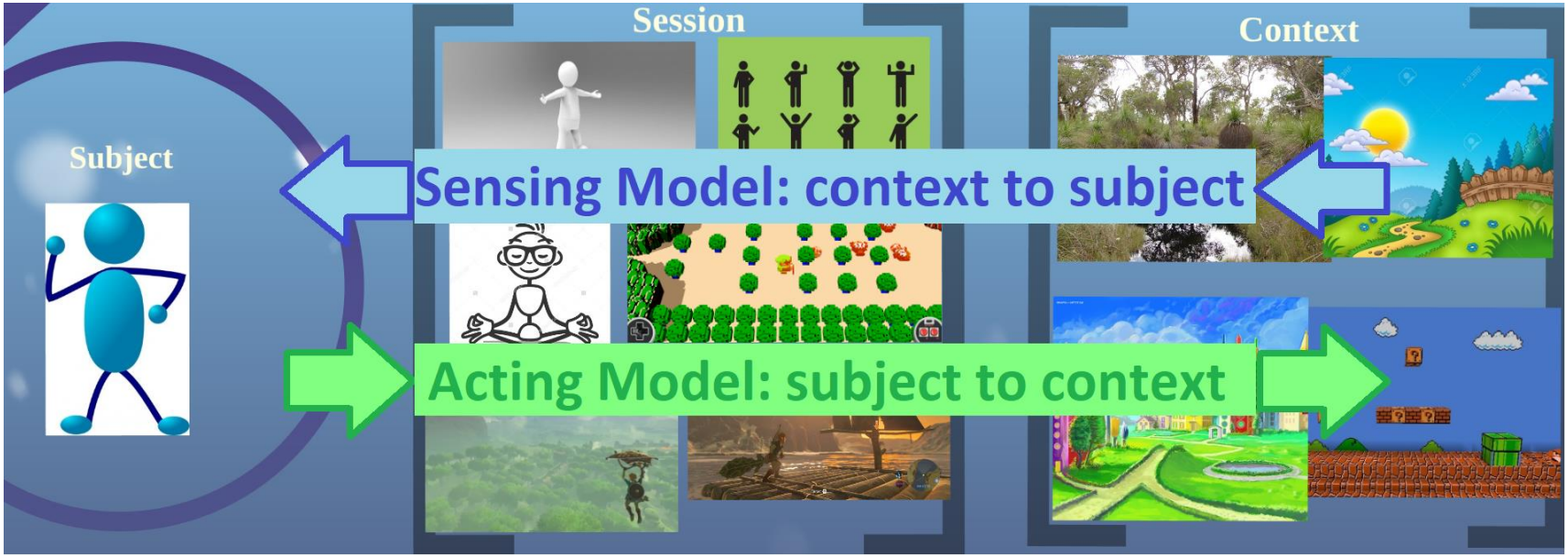
- ➢ Subject ←(*BCI interaction*)→ Context
- ➢ Skeleton: Modeling Components
- ➢ BCI-O's Descriptive Features
- ➢ Context Model: Unity's Gaming Modeling Architecture

A **human-environment interaction model** for any BCI activity

BCI ONTOLOGY: OVERVIEW

@spec#Overview_Presentation

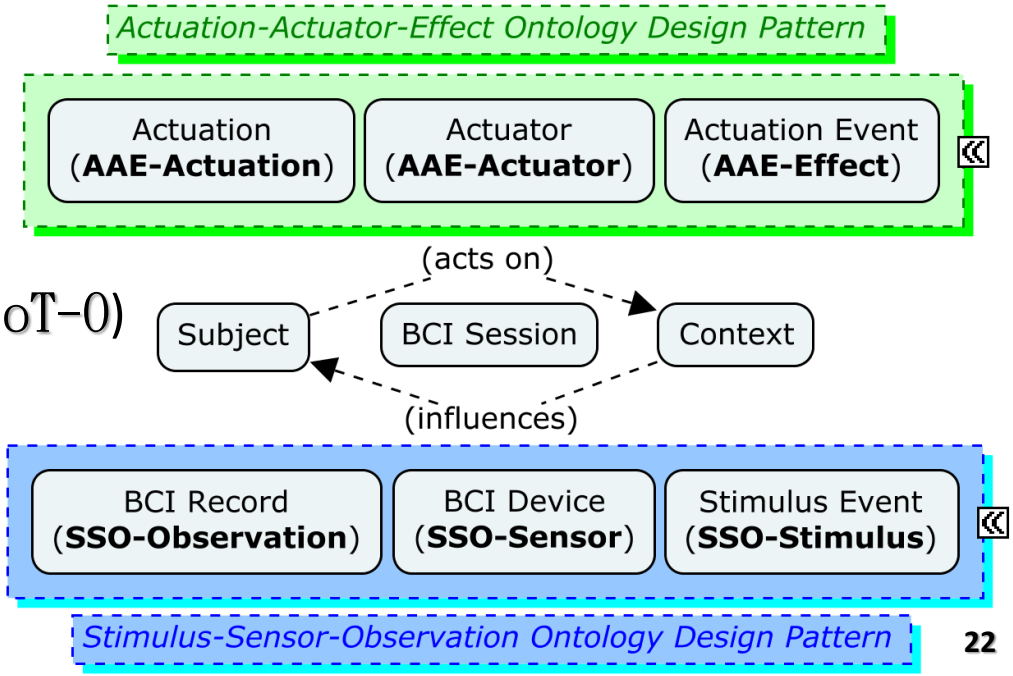
Subject ←(*BCI interaction*)→ Context



Integrates

- **Sense Model** (→ SOSA/SSN)
- **Actuation Model** (→ SOSA & SAN・IoT-O)
- **Context Model** (【Unity】)

for BCI data capture

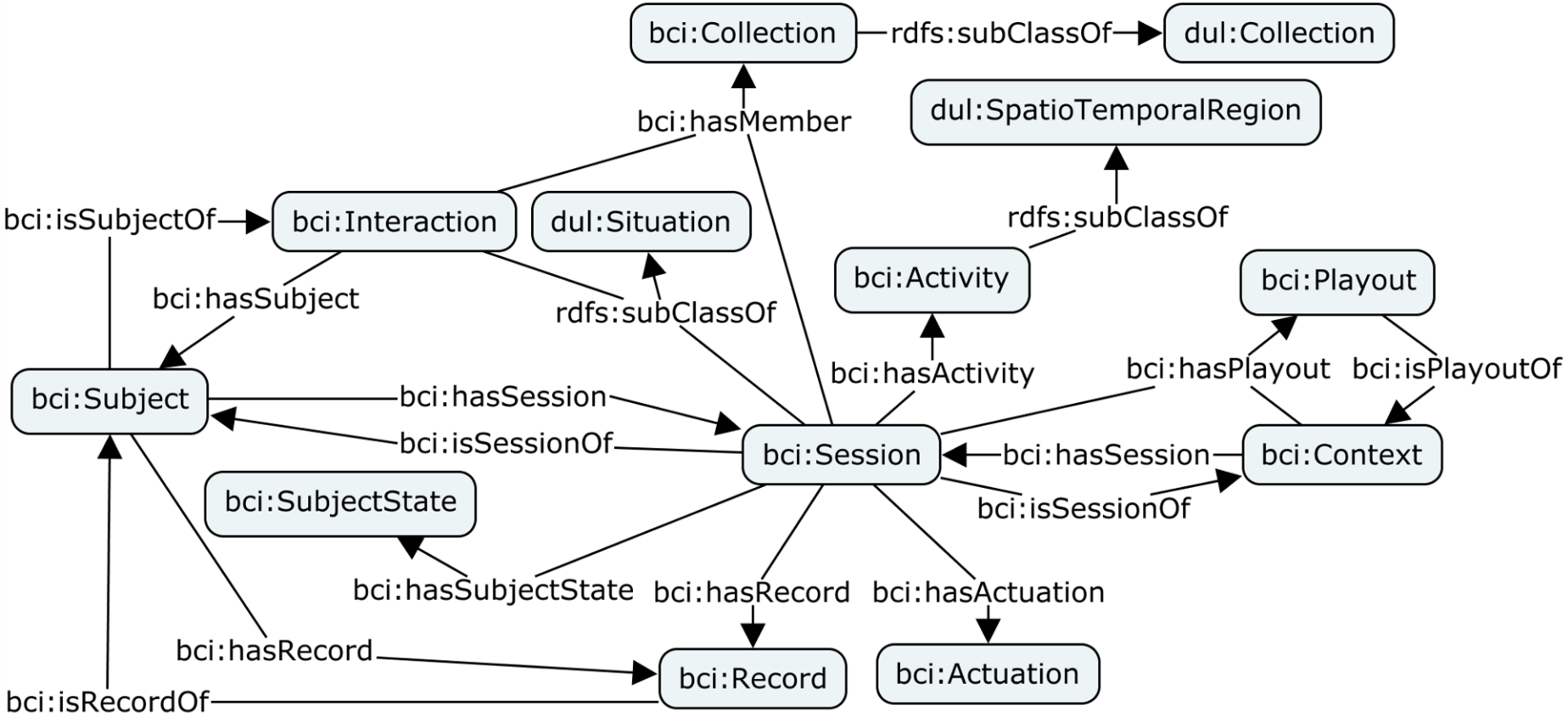


Skeleton: Modeling Components

Wearing a set of sensors (*device*) and/or through actuators (*actuator*), human beings (*subject*) interact with an environment (*context*) while performing (*session*) real-world activities (*activity*), where stimuli (*stimulus*) triggered by *context*ual *events*, are observed, recorded (*record*) and marked (*marker*) in the sensed multimodal (*modality*) BCI *data*

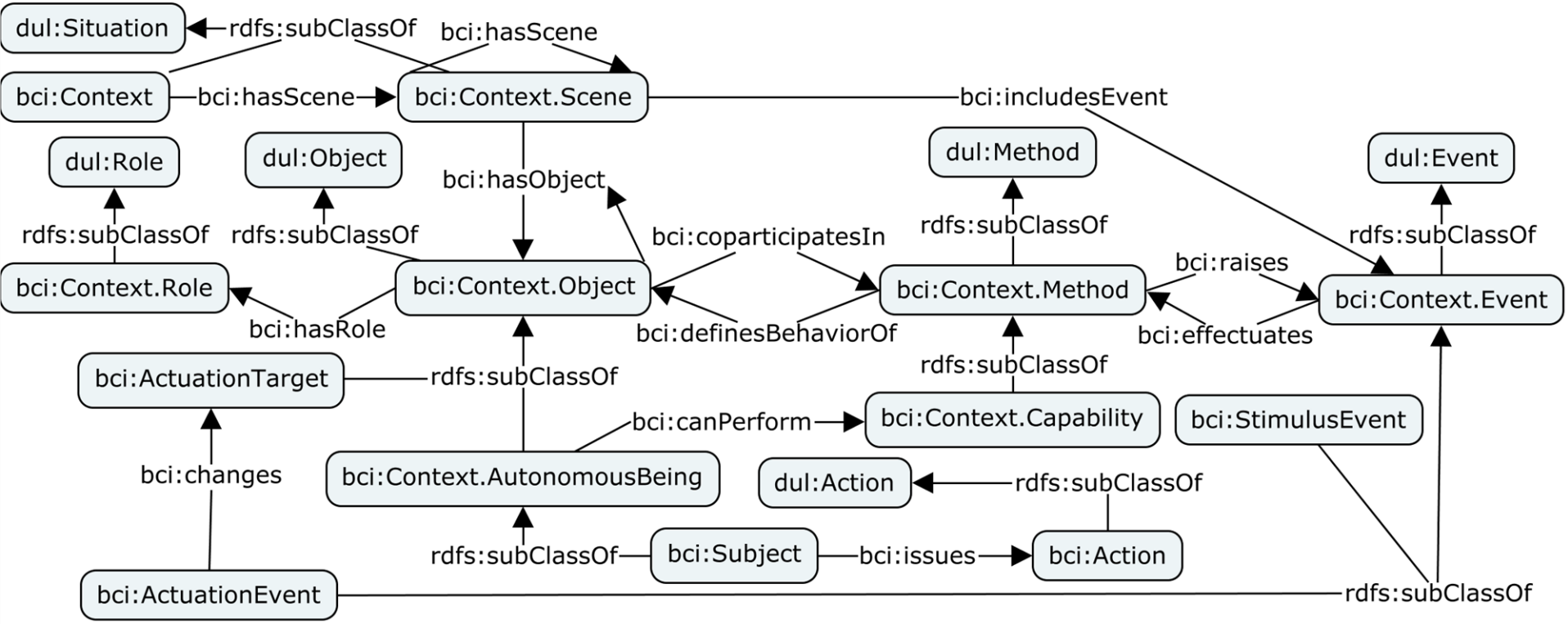
- Conceptual abstractions for *subject* (person), *context* (environment), *session*, *multimodality*, and *event annotation tags*.

Session: The integration of the Sense and Actuation Models for BCI-O's Descriptive Features



https://w3id.org/BCI-ontology#Session

Context Model:
Unity's Gaming Modeling Architecture



https://w3id.org/BCI-ontology#Context

BCI-O Contributions

- An axiomatization to capture relevant descriptive and predictive features of the multimodal data
  - Core BCI Interaction Model
  - **Sense Model** — aligned to SOSA/SSN based on SSO ODP
  - **Actuation Model** — integrated alignment to SOSA/SSN and SAN (IoT-O) based on AAE ODP
  - **Context Model** — a novel model for describing any kind of real/virtual environments based on Unity

- **Impact**:
  A semantic-based approach to organize, query and find patterns (inferencing) among the BCI Metadata

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- ➢ Actuation Model: SOSA ontology & AAE Design Pattern (SAN/IoT-O)
- ➢ Alignment to SOSA/SSN.
- ➢ Following the AAE ODP and alignment to SAN (IoT-O).

Based on design patterns from SOSA/SSN and SAN/IoT-O.

BCI ONTOLOGY: ACTUATION MODEL

@spec

Actuation Model:

SOSA ontology & AAE Design Pattern (SAN/IoT-O)

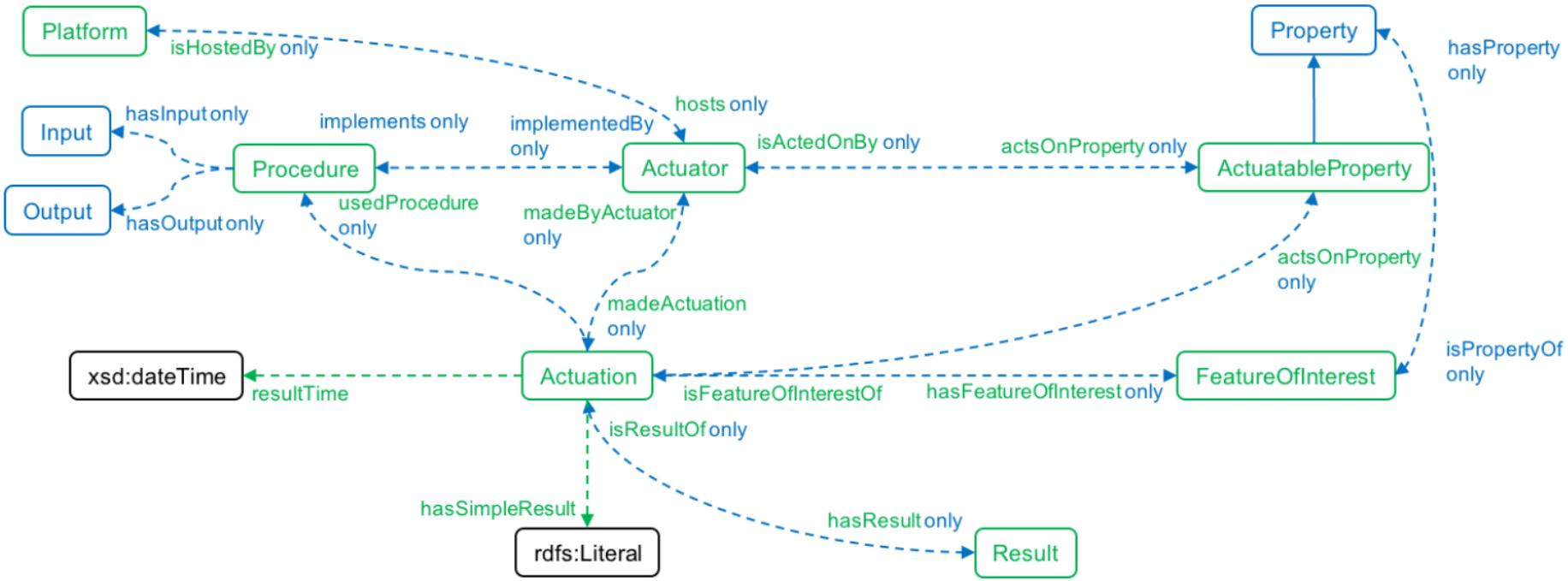


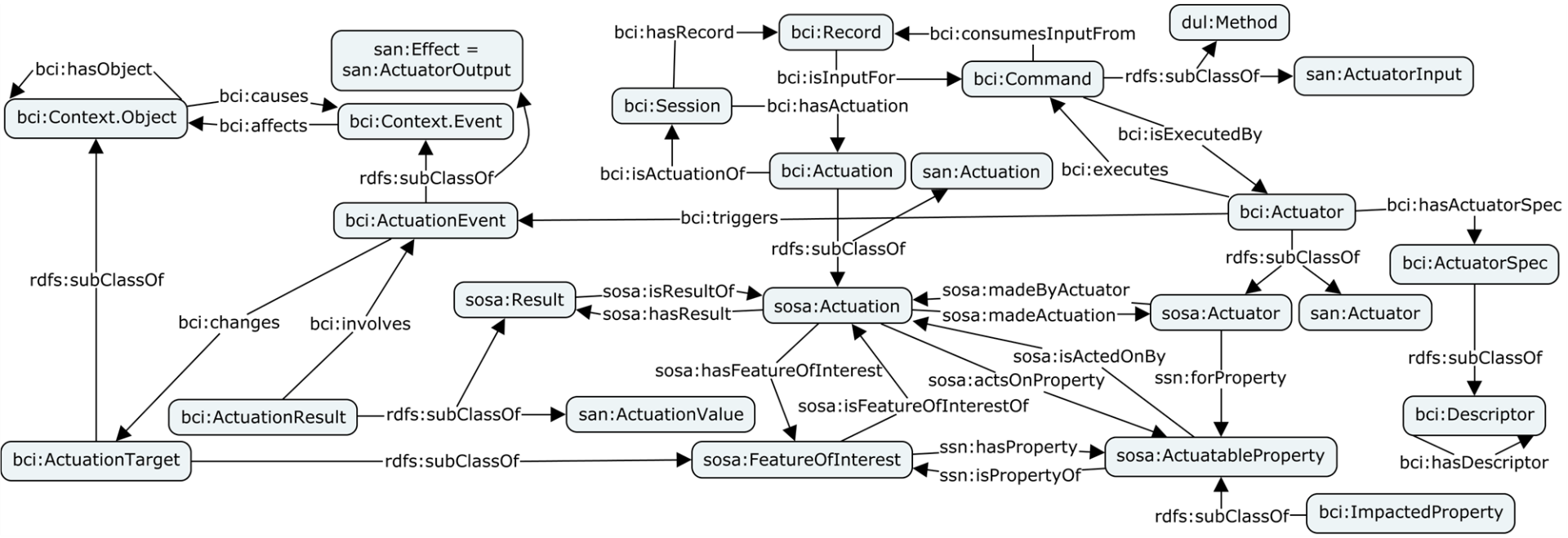
Figure 12 Classes and relationships involved in Actuation (SOSA/SSN)

[AAE Design Pattern](#) | [SOSA/SSN Actuations](#)

[https://w3id.org/BCI-ontology#Actuation](#)

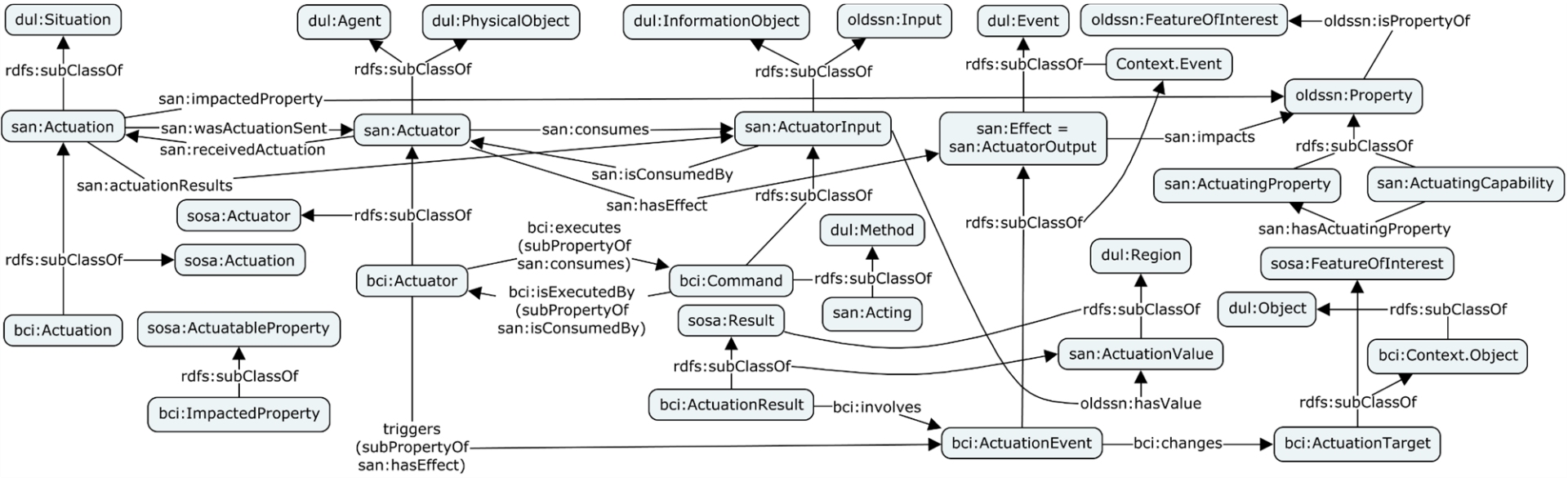
@spec#2_MAPPINGS-TO-SAN

Actuation Model: Alignment to SOSA/SSN



https://w3id.org/BCI-ontology#Actuation

Actuation Model: following the AAE ODP and alignment to SAN (IoT-O)



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- ✓ BCI Ontology: Actuation Model
- ❑ BCI Ontology: Use Case Modeling
- ❖ Final Remarks

➢ Use Case: Modeling Actuations in BCI-O

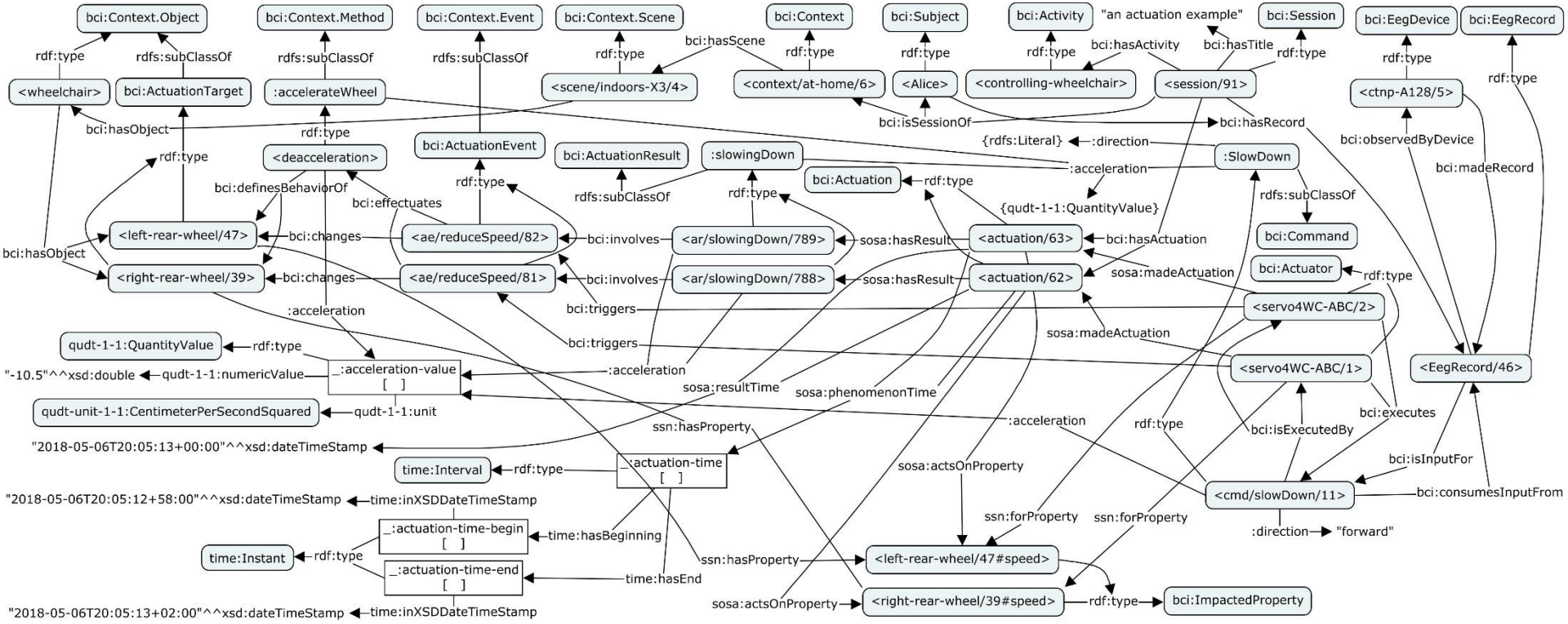
An example for modeling actuators in BCI-O.

BCI ONTOLOGY: USE CASE MODELING

USE CASE: MODELING ACTUATIONS

Actuation: Automated Wheelchair

@spec / General Examples / Actuation



Important: BCI-O's Actuation Model…

- Provides a mechanism to correlate the observed/analyzed raw data, with the contextual components that the subject interacts with, through actuators (IoT devices), identifying how the actuations affect the context.
- This is useful in BCI context-aware applications to model how subjects use actuators and interact with the environment, for “intelligent” subject-context personalization.

PET
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- ✓ BCI: Brain-Computer Interface
- ✓ BCI Ontology: Origins & Motivation
- ✓ BCI Ontology: Overview
- ✓ BCI Ontology: Actuation Model
- ✓ BCI Ontology: Use Case Modeling
- ❑ Final Remarks

- ➢ Conclusions
- ➢ Q&A

Wrapping up…

FINAL REMARKS

Final Remarks

- BCI-O makes BCI metadata "**FAIR data**" <https://www.go-fair.org/fair-principles/> : Findable Accessible Interoperable Reusable.
- A domain ontology for BCI sensors and actuators with a special interest in real-time IoT M2M environments with Big Data sets.
- A novel Context Model that makes BCI systems to be semantically *context-aware* for real/virtual-world situations. Thus, it gives a semantic foundation for Augmented BCI applications, assisting ambient intelligence's settings in sensor systems for any kind of BCI.
- BCI-O's Actuation Model integrates carefully both standard axiomatization models for actuations, developed by W3C/OGC and IoT communities, based on its Context Model.
- Its structure follows closely the AAE ODP, while aligning to SOSA/SSN and SAN (IoT-O) concepts, based on contextual notions.
- The SOSA-SAN integrated Actuation Model of BCI-O represents a major contribution to the IoT and BCI communities, especially because its structure includes contextual notions that enables its usage in context-aware BCI-IoT integrated applications.

28 September 2018
MIND-READING TECH

Machines that know your thoughts and dreams

For decades, neuroscientists have been trying to decipher what people are thinking from their brain activity. Now, thanks to an explosion in artificial intelligence, we can decipher patterns in brain scans that once just looked like meaningless squiggles.

<The-End />

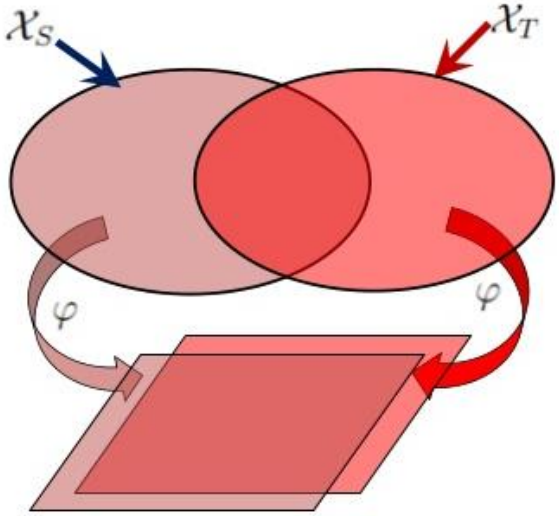
THANK YOU FOR YOUR ATTENTION!

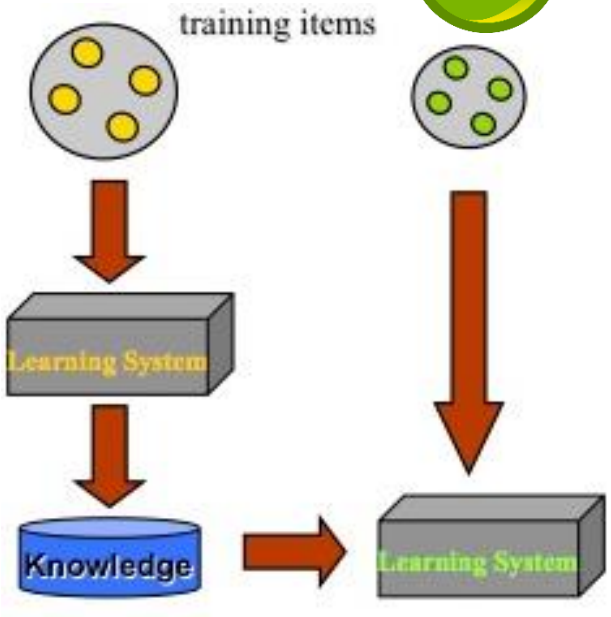
https://w3id.org/people/sergio

Transfer Learning (TL) & Adaptive BCI

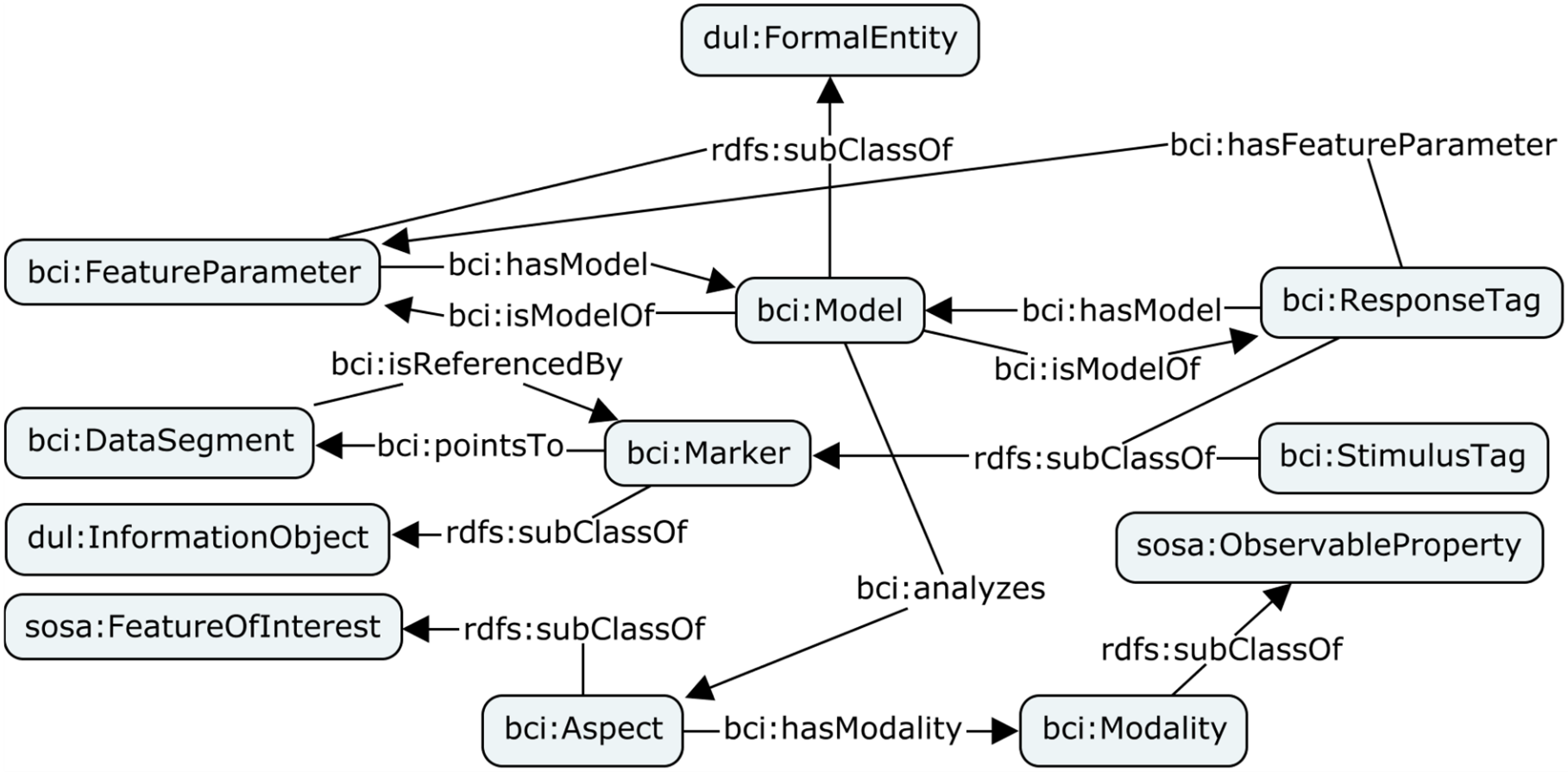
- TL from a BCI perspective: "From *metadata* used by an application A (source), use **similar** *metadata* sets that may apply to B to aid training models used in B (target)".
- Adaptive BCI: adapt a BCI system for personal use through "*model refinement*" (calibration/adjustments of prediction and classification models). Use *feature-based TL* in online EEG classification:
  - source: archived data collected from other users;
  - similarity: yielded similar responses under similar situations; (plus)
  - target: a small amount from the new user.

When source and target domains only have some overlapping features. (lots of features only have support in either the source or the target domain)





Marker & Model: Key Abstractions for BCI-O's Predictive Features



https://w3id.org/BCI-ontology#Marker
https://w3id.org/BCI-ontology#Model

Sense Model:
SOSA/SSN Ontology & SSO Design Pattern

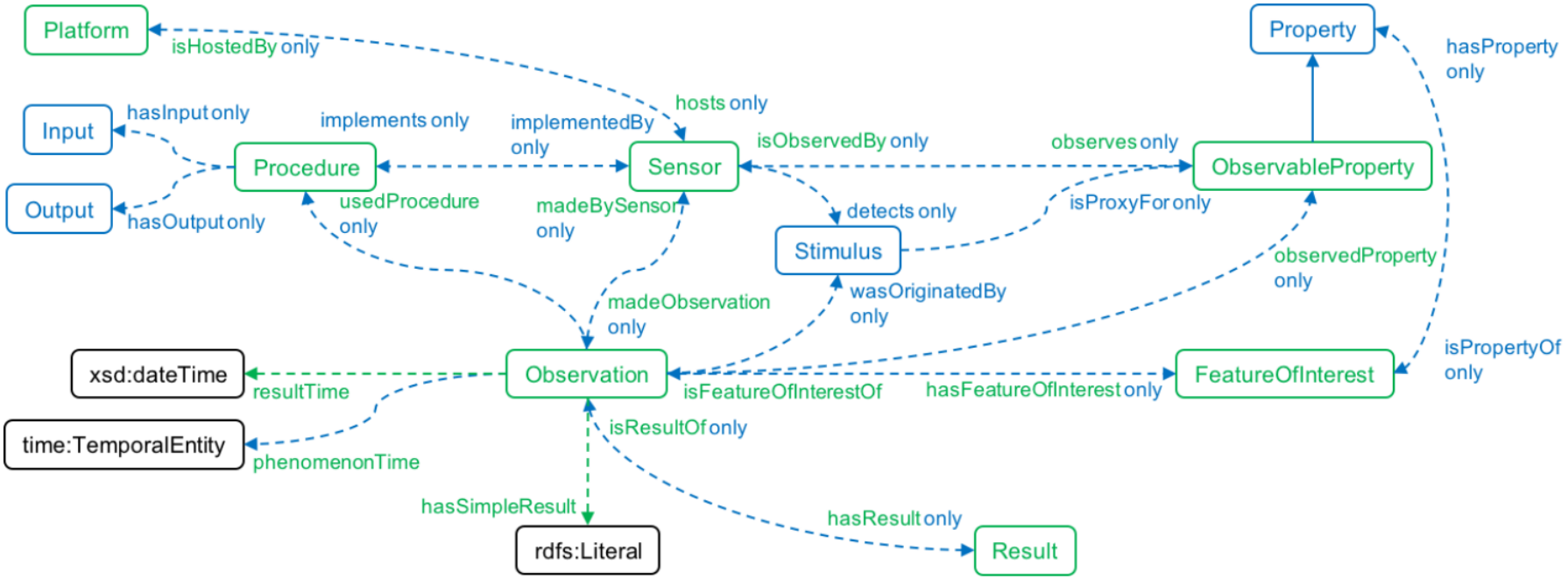
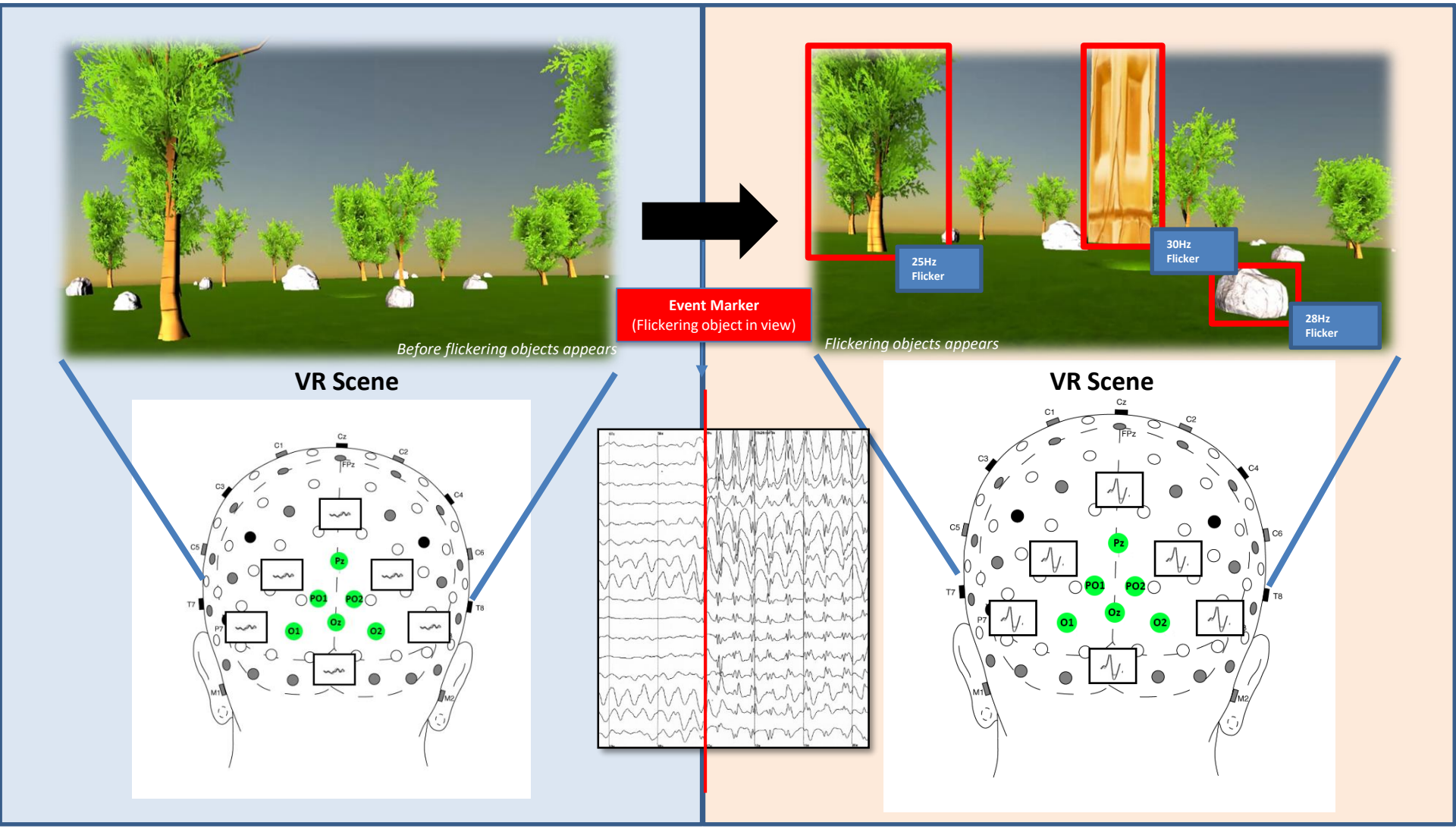


Figure 10 Classes and relationships involved in Observation (SOSA/SSN)

SSO Design Pattern | SOSA/SSN Observations

- https://w3id.org/BCI-ontology#StimulusEvent
- https://w3id.org/BCI-ontology#Device
- https://w3id.org/BCI-ontology#Record

Modeling – Observation & Context



Visual Stimuli Video: [3DForest]

@spec#General_Examples

INFERENCING

Semantic Matching Using Inference Rules

Discover new knowledge to enrich BCI metadata with new individuals and relationships →Implicit or hidden patterns

```
# A SPARQL construct rule that relates existing mc
# for a specific set of restrictions on sessions,

PREFIX : <https://w3id.org/BCI-ontology#>
PREFIX analyzer : <http://example.org/analyzer/>

CONSTRUCT { ?model analyzer:relatesTo ?activity }
WHERE {
    ?activity a :Activity .
    ?model a :Model .
    ?session a :Session ;
        :hasActivity ?activity ;
        :hasRecord ?record .
    ?record a :Record ;
        :aspectOfInterest ?aspect .
    ?aspect a :Aspect .
    FILTER EXISTS { ?model :analyzes ?aspect } .
    FILTER(/* Session restrictions */) .
    FILTER(/* Subject restrictions */) .
    FILTER(/* Context restrictions */)
}
```

An SPARQL construct rule is applied by an analyzer to relate available models with activities, as a relevant relationship for further BCI analysis and processing

CerebraWeb.net

<http://cerebraweb.net/>