Ontology harmonization between fMRI and ERP: CogPO and NEMO

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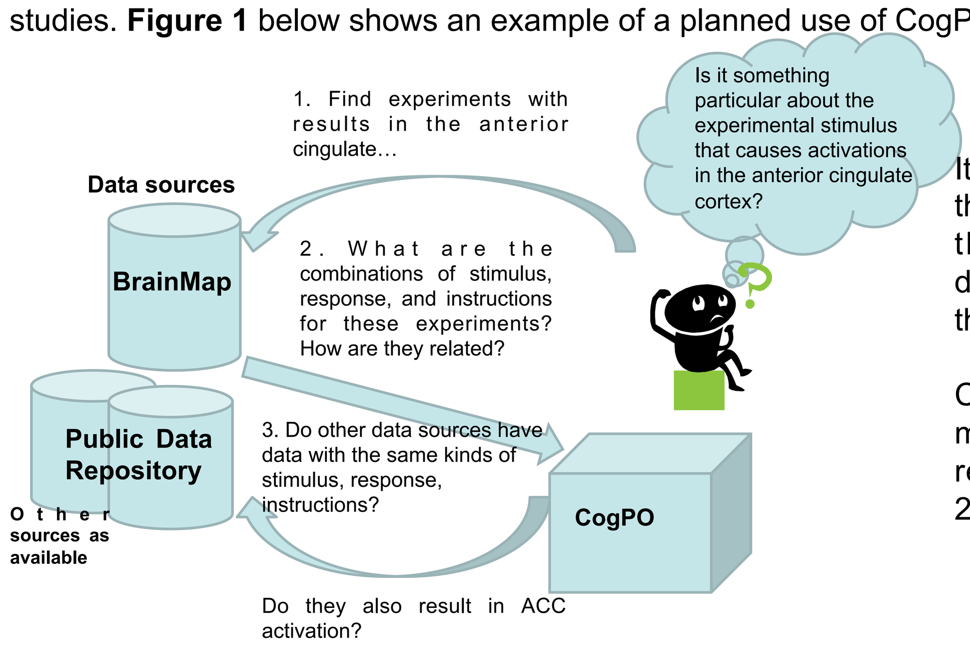
BACKGROUND: Formal representation of experiment design

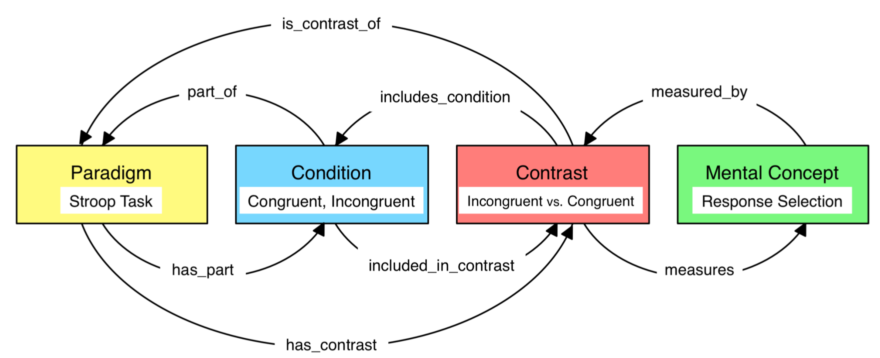
The ability to query, retrieve, and reason over scientific experiments and data from distributed repositories needs standardized terms with clearly defined logical relationships among them. The goal of the Cognitive Paradigm Ontology is to provide a basic ontology for the description of cognitive behavioral experiments for use in human PET, fMRI, ERP, and cognitive psychology studies. **Figure 1** below shows an example of a planned use of CogPO (Turner & Laird, 2011).



It is not just the description of the experimental methods but the relationships between different experimental methods that we aim to represent.

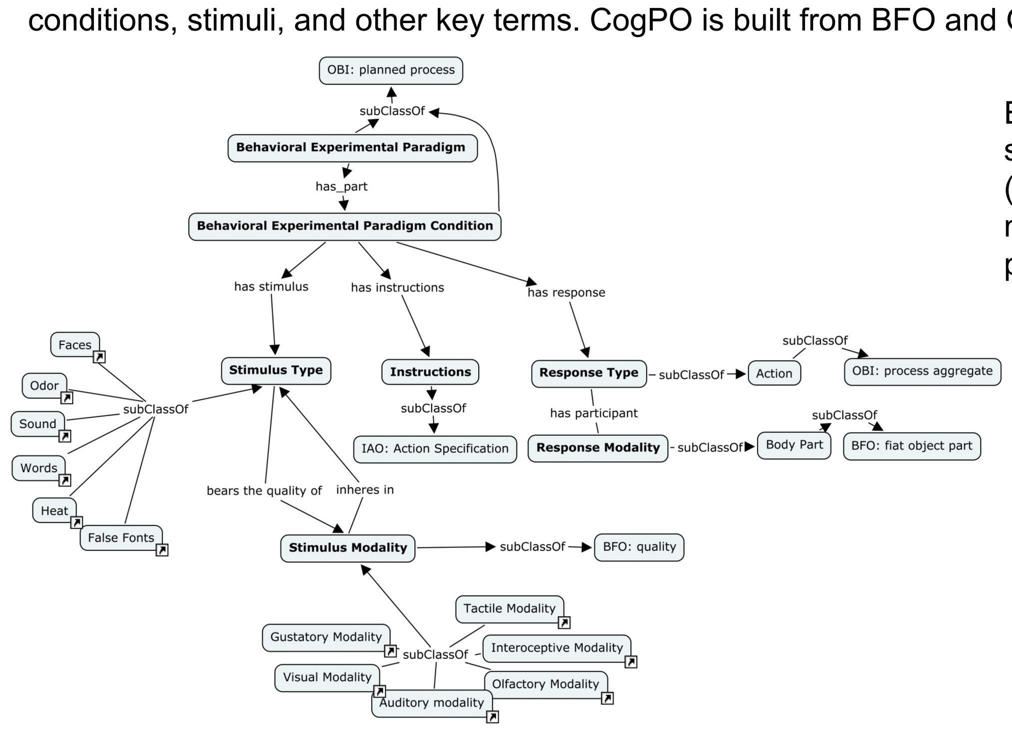
CogPO builds on BrainMap, a mature repository of imaging results (Fox and Lancaster, 2002; Fox et al., 2005).

Figure 2. The relationships between cognitive paradigm, conditions, contrasts of those conditions, and mental concepts that are common to CogPO, NEMO, and CogAtlas. (From Laird et al., under review.)



THE COGNITIVE PARADIGM ONTOLOGY (COGPO).

Figure 3 below shows the basic structure of CogPO, and the relationship between experimental conditions, stimuli, and other key terms. CogPO is built from BFO and OBI (Turner and Laird, 2011).



Experimental conditions comprise stimuli, responses, and Instructions (in bold). Stimuli have sensory modalities; responses use body parts (e.g., hand, foot, mouth).

NEURAL ELECTRO MAGNETIC ONTOLOGIES (NEMO).

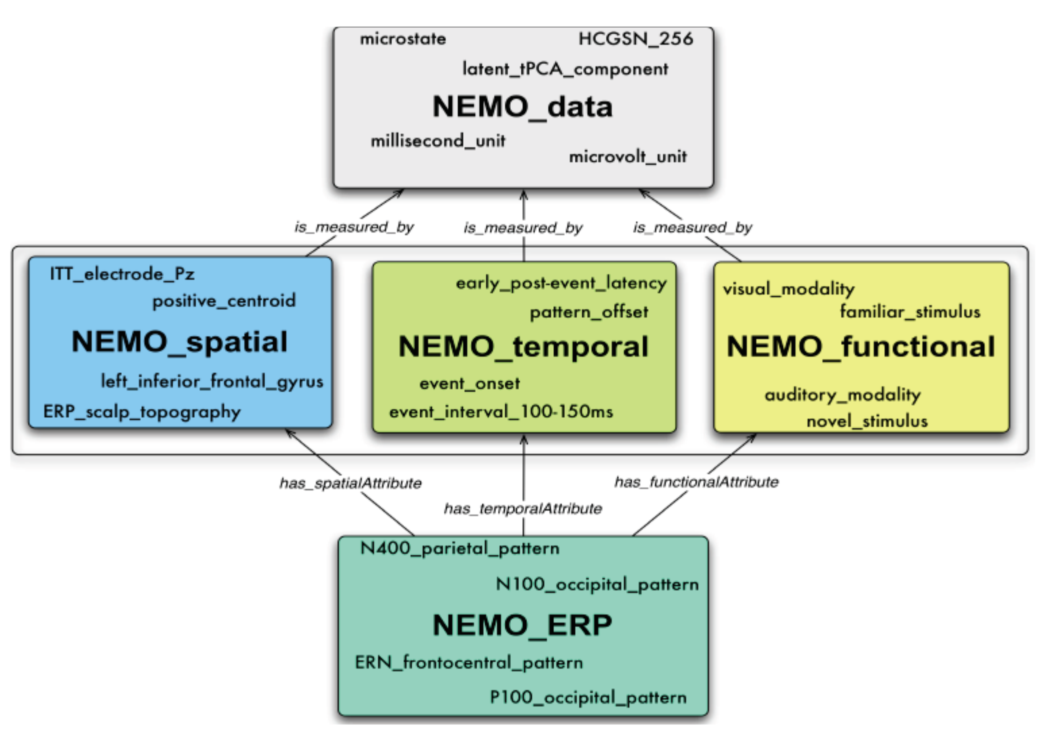


Figure 4. The NEMO ontology is designed to support representation, classification, and meta-analysis of brain electromagnetic data. NEMO **data** consist of raw EEG, averaged EEG (ERPs), and ERP data analysis results. NEMO **ontologies** include concepts related to ERP data (including spatial and temporal features of ERP patterns), data provenance, and the cognitive and linguistic paradigms that were used to collect the data. The NEMO **database** is a large repository that stores NEMO consortium data, data analysis results, and data provenance. All resources are open source. See *nemo.nic.uoregon.edu*.

METHODS: Identifying mappings between ontologies

GOAL #1

Improve interoperability between cogPO and NEMO by harmonizing their structures.

METHOD (GOAL #1):

Key terms from CogPO were identified in NEMO. We then asked the question: Do they have the same labels, definitions, superclasses and subclasses.

CogPO	NEMO
Behavioral Experimental Paradigm is a planned process that has_part at least one experimental condition. Paradigm subclasses are from **BrainMap**.	***Experimental_paradigm*** is a protocol (plan_specification), which is realized as a planned_process (the latter is in cogPO as well as NEMO). Examples include, but are not limited to, concepts from **BrainMap**.
Behavioral Experimental Paradigm Condition is a planned process that is part of a *Behavioral Experimental Paradigm* and has at least one *stimulus*, one *response*, and one *instruction*. Condition subclasses are from **BrainMap**.	***Experiment_condition*** is a protocol with no explicit constraints. NEMO includes explicit conditions such as auditory oddball condition, which CogPO allows for but does not explicitly include. Examples include, but are not limited to, concepts from **BrainMap**.
Stimulus is an object aggregate, i.e. a class of things that play the role of stimulus. Any example stimulus (e.g., *Tone*) are all subtypes of the stimulus class. Stimulus subclasses are from **BrainMap**.	***Stimulus_role*** is a specifically_dependent_continuant (a BFO class that is also present in cogPO). The object relation *role_of* is used to link stimulus_role to the class of objects and object aggregates that can function as stimuli within an experiment (including, but not limited to concepts from **BrainMap**).
Stimulus modality is a quality that inheres in a stimulus. It includes auditory, gustatory, visual, olfactory, interoceptive, tactile; and as subtypes of tactile, pain, pressure, and vibratory. Stimulus modality subclasses are from **BrainMap**.	***Stimulus_modality*** is a quality that inheres in some material entity (*object* or *object aggregate*). It includes auditory, gustatory, visual, olfactory, interoceptive, and somatosensory modalities (from **BrainMap**).
Response is a process aggregate. It includes asserted classes, *Overt* and *Covert Response*. All the allowed responses from **BrainMap** are Covert Responses.	***Response_role*** is a specifically_dependent_continuant (BFO class that is also present in cogPO). The object relation *role_of* is used to link *response_role* to the class of processes that can function as responses within an experiment. Examples like *button_press* are behavioral processes, which are processes.
Response modality is *part_of* an object, imported from the Foundational Model of Anatomy (FMA). It includes body parts used to make the response.	***Response modality*** is a quality that inheres in some process that *has_role response_role*. It includes some, but not all response modalities specified in **BrainMap**.
Instructions are an action specification, which is a directive information entity. All the allowable types of instructions from **BrainMap** are included.	***Instructions to subject*** is subclass of *protocol*, and include all the subtypes from CogPO. Cf. *experiment_instruction*, a type of *study_design_execution* (planned process). Examples include, but are not limited to, concepts from **BrainMap**.

RESULTS (GOAL #1):

Only Stimulus Modality was an exact match. Other terms were close but had different locations in their respective ontologies, which leads to different formal semantics and representations of experiment models. NEMO had imported most of the CogPO terms but also had terms for experimental paradigms in their data which are needed in CogPO as well.

GOAL #2:

The roles and relationships from CogPO were compared to NEMO's: Did NEMO have the same relationships and were they applied to the same terms as in CogPO?

CogPO	NEMO
Stimulus role is a role that can only be played by objects within the stimulus class.	***Stimulus role*** is an investigation_role (a subclass of role). No a priori restrictions. Other experiment roles include *response role*, *feedback role*, and *independent/dependent variable* roles.
Response role is a role which can only be played by responses.	Same as **stimulus role**.
Has_stimulus, has_response is a relationship between experimental conditions and stimulus, and condition and response, respectively.	N/A.
Has_stimulus_modality *and has_response_modality* are relationships between stimulus and stimulus modality, and response and response modality, respectively.	N/A.

RESULTS (GOAL #2):

Of the main relationships among concepts for experimental design in both ontologies, there were some with the same names but not the same restrictions. Others were not defined at all in one ontology or the other.

SOLUTIONS: Harmonization of ontologies

1) **COMMON FRAMEWORK FOR ANNOTATING TERMS**: Term matching simpler when term definitions, properties, and logical constraints are tagged similarly. CogPO and NEMO have agreed on a common set of fields and labels for their terms, with an additional file listing the equivalencies where the same property isn't used. For example,
   1) CogPO and NEMO both use *rdfs:label* as the field for the term labels.
   2) NEMO imports the Dublin Core terms (dc/terms) and uses *dcterms:modified* and *dcterms:created* for dates a term was created and modified. CogPO imports the Dublin Core elements (dc/elements) and uses *dc:date* for both. To harmonize this, CogPO created new subannotations, *Date Modified* and *Date Created*, which are used the same way.
   3) NEMO used core:definition for the field for human-readable definitions. CogPO imports the Information Artifact Ontology (IAO) and uses their annotation property (IAO_0000115) for exactly the same thing. This is noted in the annotation equivalencies file, as are the mappings between other annotation fields/

2) **SHARED STANDARDS FOR IMPORTING TERMS**: Subclasses that are in CogPO but not in NEMO can be imported, using MIREOT standards (Minimum information to reference an external ontology term (Courtot et al., 2009)). Similarly, subclasses such as paradigms and conditions which NEMO needed but are not yet in CogPO can be imported as well.

3) **COORDINATED USE OF BRIDGING AXIOMS**: The underlying model of the experiment is different even if the specific details being captured are the same. To bridge NEMO and CogPO we need translations.

Example: When looking for data from an experimental paradigm with an auditory stimulus, the descriptive logic (DL) query looks like this**:**

CogPO: 'Behavioral Experimental Paradigm'
and has_part some (has_stimulus some (has_stimulus_modality some 'Auditory Modality'))
The CogPO query is looking for experimental paradigms that have at least one condition with a stimulus with an auditory modality, with the data linked to that.

NEMO: [averaged_EEG_data_set] *occurs_in_response_to* SOME *onset_stimulus_presentation*
THAT *has_object* SOME (*has_role* stimulus_role AND *has_quality* 'auditory')
The NEMO query is looking for data which are annotated as occurring in response to a particular stimulus, which in NEMO is an object which plays the role of stimulus.

4) **APPLICATION OF ONTOLOGIES FOR DATA ANNOTATION**: NEMO and CogPO ontologies are both used for data annotation. CogPO is used for annotating fMRI and PET coordinate results; NEMO is used for annotating ERP data, including raw and processed patterns. The agreement on experimental conditions, contrasts, and paradigms shown in Figure 2 allows both ontologies to address common experimental results; the link to mental processes allows interactions with CogAtlas (Poldrack, et al.) and other ontologies of mental functions.

CONCLUSIONS

- Even in ontologies that are being developed in a coordinated way and are designed to represent overlapping domains — such as **ERP** and **fMRI** data — the "same" ideas (informal semantics) may be represented using different formal semantic structures (axioms).
- Different ontology structures may lead, in turn, to different uses of analogous terms. Bridge files, which identify mappings between terms, are likely to prove helpful. Automated translation services may be even better.
- The critical aim is to enable **integration of neuroscience data** (within and across domains) that have been annotated with terms from different neuro-ontologies.

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