The NeuroFMA:
Ontological Framework for Neuroanatomy

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**Expectations:** Neuroanatomy Ontology should

- **Index and retrieve neuroscience information by species** for mouse, rat, macaque, human;

- **Define several hierarchical schemes** for grouping primary structures to support accessing information in bigger chunks;

- **Specify the relation of several thousand synonyms** to allow the retrieval of information in terms of different nomenclatures;

- **Provide atlases of segmented coronal brain sections** for warping of MRI and PET scans.

*Neuroanatomy Ontology Workshop Summary*
General Challenges in Biomedical Informatics

- Interoperability
- Representation of biomedical knowledge in machine-processable form
- Integration and correlation of biomedical information and data
- Inadequacy of traditional knowledge sources
General Challenges in Biomedical Informatics

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Neuroanatomical Terminologies

Anatomy and library reference:
- NeuroAnatomy Textbooks
- Terminologia Anatomica
- MeSH

Clinical terminologies:
- SNOMED
- GALEN
- BrainML

Basic and clinical neuroscience:
- NeuroNames
• **Incorporate neuroanatomical views from various sources in accord with the FMA ontological principles.**
What is the brain?
What is the brain?

Is it an organ?
What is the brain?

Brain + Spinal cord = Whole
an organ part?

Brain

Spinal cord
What is the brain?

**Brain**

**Brain + Spinal cord = Neuraxis**

**Spinal cord**
Foundational Principles of Anatomy

1. Definition principle
2. Dominant class principle
3. Organizational unit principle
4. Content constraint principle
Foundational Principles of Anatomy

1. Definition principle
2. Dominant class principle
3. Organizational unit principle
4. Content constraint principle
Role of Definitions

- To specify a unique taxonomy
- To assure semantic and logical consistency within the ontology
- To assure transitive inheritance of properties through type hierarchy (taxonomy)

The Foundational Model of Anatomy Ontology

\[ FMA = (AT, ASA, ATA, Mk) \]

where:

- **AT** = Anatomy Taxonomy
- **ASA** = Anatomical Structural Abstraction
- **ATA** = Anatomical Transformation Abstraction
- **Mk** = Metaknowledge
  
  (principles, rules, axioms)


http://sigpubs.biostr.washington.edu/archive/00000204/
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where:

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- ATA = Anatomical Transformation Abstraction
- Mk = Metaknowledge (principles, rules, axioms)
Anatomy Taxonomy

- Anatomical entity
  - Physical anatomical entity
  - Material anatomical entity
    - Anatomical structure
      - Body
      - Cardinal body part
      - Organ system
      - Subdivision of cardinal body part
      - Organ system subdivision
      - Organ
      - Cardinal organ part
      - Portion of tissue
      - Cardinal tissue part
      - Cell
      - Cardinal cell part
      - Biological macromolecule
      - Acellular anatomical structure
      - Anatomical cluster
      - Anatomical junction
      - Vestigial embryonic structure
      - Gestational structure
      - Portion of body substance
      - Anatomical set
    - Immaterial anatomical entity
      - Non-physical anatomical entity
Foundational Principles of Anatomy

1. **Definition principle**
2. **Dominant class principle**
3. **Organizational unit principle**
4. **Content constraint principle**
Organizational Unit Principle

Anatomical Entity

- is a -

Physical Anatomical Entity

Material Physical Anatomical Entity

Non-material Physical Anatomical Entity

Non-physical Anatomical Entity

Body Substance

Space

Surface

Line

Anatomical Structure

Biological Macromolecule

Acellular Anatomical Structure

Cell Part

Cell

Tissue

Organ Part

Organ

Human Body

Body Part

Organ System

Organ component

Organ subdivision
Organizational units

- Anatomical entity
  - Physical anatomical entity
  - Material anatomical entity
    - Anatomical structure
      - Body
      - Cardinal body part
      - Organ system
      - Subdivision of cardinal body part
      - Organ system subdivision
    - Organ
      - Cardinal organ part
      - Portion of tissue
      - Cardinal tissue part
    - Cell
      - Cardinal cell part
    - Biological macromolecule
      - Acellular anatomical structure
      - Anatomical cluster
      - Anatomical junction
      - Vestigial embryonic structure
      - Gestational structure
    - Portion of body substance
    - Anatomical set
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Foundational Principles of Anatomy

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Ontology based on structure only
How is the brain represented in the FMA?
Foundational Model of Anatomy Ontology

Anatomical Structural Abstraction

\[ FMA = (At, ASA, ATA, Mk) \] (1)

\[ ASA = (Do, Bn, Pn, SAn) \] (2)

where:

- \( Do \) = Dimensional ontology
- \( Bn \) = Boundary network
- \( Pn \) = Part-of network
- \( SAn \) = Spatial Association network
Foundational Model of Anatomy Ontology

Anatomical Structural Abstraction

\[ FMA = (At, ASA, ATA, Mk) \] (1)

\[ ASA = (Do, Bn, Pn, SAn) \] (2)

where:

- **Do** = Dimensional ontology
- **Bn** = Boundary network
- **Pn** = Part-of network
- **SAn** = Spatial Association network
Two kinds of parts are represented

- Cerebral cortex
- Right hemisphere
- Left hemisphere
Two kinds of parts are represented

- Cerebral cortex of Right hemisphere
- Cerebral cortex of Left hemisphere
Kinds of parts

Brain
  Forebrain
    Telencephalon
      cerebral cortex
cerebral subcortex
lateral ventricle
      right cerebral hemisphere
left cerebral hemisphere
    neural tissue of telencephalon
ventricular system of telencephalon
vasculature of telencephalon

Diencephalon

Midbrain

Hindbrain
Kinds of parts

Telencephalon
  cerebral cortex
  cerebral subcortex
  lateral ventricle
Kinds of parts

Telencephalon
  cerebral cortex
  cerebral subcortex
  lateral ventricle

right cerebral cortex
left cerebral cortex
right cerebral subcortex
left cerebral subcortex
right lateral ventricle
left lateral ventricle
is_a relation NOT part_of relation!

Telencephalon
  cerebral cortex
  cerebral subcortex
  lateral ventricle

right cerebral cortex
left cerebral cortex

right cerebral subcortex
left cerebral subcortex

right lateral ventricle
left lateral ventricle
Kinds of parts

part_of relation

Telencephalon
  right cerebral hemisphere
    right cerebral cortex
    left cerebral cortex
    right cerebral subcortex
    left cerebral subcortex

    right lateral ventricle
    left lateral ventricle
Kinds of parts

part_of relation

Telencephalon
  right cerebral hemisphere
  right cerebral subcortex
  right lateral ventricle

left cerebral hemisphere
  left cerebral cortex
  left cerebral subcortex
  left lateral ventricle
Kinds of parts

part_of relation

Telencephalon

right cerebral hemisphere
  right cerebral cortex
  right cerebral subcortex
  right lateral ventricle

left cerebral hemisphere
  left cerebral cortex
  left cerebral subcortex
  Left lateral ventricle
Kinds of parts

part_of relation

Telencephalon

right cerebral hemisphere
  right cerebral cortex
  right cerebral subcortex
  right lateral ventricle

left cerebral hemisphere
  left cerebral cortex
  left cerebral subcortex
  left lateral ventricle

white matter of RCH
set of gray matter of RCS
Kinds of parts

part_of relation

right subcortical association fiber layer
right half of corpus callosum
right corona radiata
right internal capsule

white matter of RCH
set of gray matter of RCS
Kinds of parts

part_of relation

right subcortical association fiber layer
right half of corpus callosum
right corona radiata
right internal capsule

white matter of RCH
set of gray matter of RCS

basal ganglia of right cerebral hemisphere
set of septal nuclei of right cerebral hemisphere
Regional part has constitutional parts.
Constitutional part has **regional parts**

Constitutional part hierarchy:

- Right cerebral hemisphere
  - Right cerebral cortex
  - Right cerebral subcortex
  - Right lateral ventricle

Regional Part:
- Cortex of right frontal lobe
- Cortex of right temporal lobe
- Cortex of right parietal lobe
- Cortex of right occipital lobe
- Cortex of right insula
- Cortex of right limbic lobe
Another kind of **regional** parts
FMA

- Region of cerebral cortex
  - Cortex of lobe of cerebral hemisphere
  - Region of cortex of frontal lobe
  - Neocortex
    - Right neocortex
    - Left neocortex
  - Allocortex
  - Mesocortex
  - Brodmann area
  - Broca's area

Constitutional Part
- Plexiform layer of right cerebral cortex
- External granular layer of right cerebral cortex
- External pyramidal layer of right cerebral cortex
- Internal granular layer of right cerebral cortex
- Internal pyramidal layer of right cerebral cortex
- Multiform layer of right cerebral cortex
...or regional part based on cytoarchitectonics
Granularity

- Physical anatomical entity
- Material anatomical entity
- Anatomical structure
  - Body
  - Cardinal body part
  - Subdivision of cardinal body part
  - Organ system
  - Organ system subdivision
  - Organ
  - Cardinal organ part
  - Portion of tissue
  - Cardinal tissue part
  - Cell
    - Cardinal cell part
    - Biological macromolecule
    - Acellular anatomical structure
    - Anatomical cluster
      - Anatomical junction
      - Gestational structure
      - Vestigial embryonic structure
    - Portion of body substance
    - Anatomical set
    - Immaterial anatomical entity
    - Non-physical anatomical entity template
Extend ontology to subcellular and macromolecular entities