Ontology and qualitative medical image analysis

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Center of Excellence in Bioinformatics and the Life Sciences
University at Buffalo
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TMJ as an example
TMJ as an example
TMJ as an example
TMJ as an example

Maureen
TMJ as an example
TMJ as an example

Maureen

Lou

Tom
TMJ as an example

Maureen

Lou

Tom
TMJ as an example

Maureen

Lou

Lou 2

Tom
TMJ as an example

Maureen

Lou

Lou 2

Lou 3

Tom
Comparing TMJ images

Maureen

Lou 2

Lou 3

Lou

Tom
Comparing TMJ images

Maureen

Lou

Lou 2

Lou 3

Tom
Comparing TMJ images

Maureen

Lou

Lou 2

Lou 3

Tom
Comparing TMJ images

Maureen

Lou

Lou 2

Lou 3

Tom
Comparing TMJ images

Maureen

Lou

Lou 2

Lou 3

Tom
Record change over time

Lou

Lou 2

Lou 3
Comparing images across individuals

Maureen

Lou

Tom
Comparing images to some ideal

Maureen

Lou

Tom
Questions
Questions

• How do we represent the ideal (canonical anatomy)?
Questions

• How do we represent the ideal (canonical anatomy)?

• How do we compare individual anatomy to canonical anatomy?
Questions

• How do we **represent** the ideal (canonical anatomy)?

• How do we **compare** individual anatomy to canonical anatomy?

• How do we **compare IMAGES** of individuals with one another and to the canonical ideal?
Answers

- How do we **represent** the ideal (canonical anatomy)?
- How do we **compare** individual anatomy to canonical anatomy?
- How do we **compare** *IMAGES* of individuals with one another and to the canonical ideal?

Formal ontology + qualitative reasoning
Answers

- How do we **represent** the ideal (canonical anatomy)?
- How do we **compare** individual anatomy to canonical anatomy?
- How do we **compare** IMAGES of individuals with one another and to the canonical ideal?

Formal ontology + qualitative reasoning

Qualitative medical image analysis
State of the art: quantitative transformations
State of the art: quantitative transformations
State of the art: quantitative transformations
State of the art: quantitative transformations
State of the art: quantitative transformations

source coordinate system

target coordinate system

Lou
State of the art: quantitative transformations
State of the art: quantitative transformations

source coordinate system

target coordinate system
State of the art: quantitative transformations

source coordinate system

target coordinate system

Lou 3
State of the art: quantitative transformations

Transformation is an empirical, statistical process
State of the art: quantitative transformations

- Transformations at the level of pixels
- Interpretation of parameters of transformations
- Do not take into account WHAT is being depicted

Transformation is an empirical, statistical process
State of the art: quantitative transformations

- Transformations at the level of pixels
- Interpretation of parameters of transformations
- Do not take into account WHAT is being depicted
- Not the way a human radiologist analyzes a medical image

(source coordinate system)  (target coordinate system)
• How do we **represent** the ideal (canonical anatomy)?

• How do we **compare** individual anatomy to canonical anatomy?
The qualitative nature of facts represented in bio-medical ontologies
The qualitative nature of facts represented in bio-medical ontologies

- It is impossible to quantitatively describe aspects of shape and spatial arrangement of canonical anatomy. Too much variation between the actual shapes and metric arrangements of structures among particular normal human beings.
The qualitative nature of facts represented in bio-medical ontologies

- It is impossible to quantitatively describe aspects of shape and spatial arrangement of canonical anatomy. Too much variation between the actual shapes and metric arrangements of structures among particular normal human beings.

- Many anatomical structures change in shape and spatial arrangement over time: the heart beats, the jaw opens and closes, etc.
The qualitative nature of facts represented in bio-medical ontologies
despite the variations and changes all normal instances of the same biological species are

**qualitative copies**

of each other
What are qualitative copies?
What are qualitative copies?

• In all canonical anatomical structures certain parts need to be present
What are qualitative copies?

• In all canonical anatomical structures certain parts need to be present

• Certain qualitative spatial relations need to hold between those parts:
  • some parts are connected/attached to others,
  • some part are adjacent to others,
  • some parts (like articular discs) need to be between other parts (like the bones in synovial joints) etc.
What are qualitative copies?

• In all canonical anatomical structures certain **parts** need to be present.

• Certain **qualitative spatial relations** need to hold between those parts:
  • some parts are **connected/attached** to others,
  • some part are **adjacent** to others,
  • some parts (like articular discs) need to be **between** other parts (like the bones in synovial joints) etc.

• The parts need to have certain **qualitative shape** features (convex parts, concave parts, other landmark features, etc.)
What are qualitative copies?

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  - some parts (like articular discs) need to be **between** other parts (like the bones in synovial joints) etc.
- The parts need to have certain **qualitative shape** features (convex parts, concave parts, other landmark features, etc.)
- The **size** of those parts must be within certain limits (qualitative size and distance measures)
How to build qualitative representations of canonical anatomical structures?

1. Identify the major parts (Mereology)

2. Establish the connectedness and attachment relations among the various parts (Mereo-topology)

3. Establish adjacency relations (Mereo-geometry)

4. Identify landmarks / establish landmark geometry

4. Establish the qualitative order relations using landmarks as frames of reference
How to build qualitative representations of canonical anatomical structures?

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Major parts

TMJ
Major parts

TMJ
Major parts
Connectedness/Attachment

TMJ
Connectedness/Attachment
Connectedness/Attachment

attachment

attachment graph
Attachment relations remains invariant under normal movement
Attachment relations remain invariant under normal movement
Attachment relations remains invariant under normal movement
Every TMJ can be represented by this attachment graph
How to build qualitative representations of canonical anatomical structures?

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adjacency relations
adjacency relations

No attachment only (temporary) adjacency
adjacency relations

No attachment only (temporary) adjacency

adjacency relations
Adjacency disc-temp. bone

Time I
Adjacency disc-temp. bone

Time 2
Adjacency disc-temp. bone

Time 3
Adjacency disc-temp. bone

• We do not need quantitative descriptions

• qualitative descriptions of allowed locations of disc with respect to the temporal bone
How to build qualitative representations of canonical anatomical structures?

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Shape landmarks of the temporal bone

Rigid does not change shape (bones)
Shape landmarks of the temporal bone

Rigid does not change shape (bones)

Convex curvature changes to concave
Shape landmarks of the temporal bone

Rigid does not change shape (bones)

Local maxima/minima
5 landmarks
5 landmarks

• the exact shape of the temporal bone varies from individual to individual
5 landmarks

- the exact shape of the temporal bone varies from individual to individual

- all normal temp. bones have these landmarks
5 landmarks

- the exact shape of the temporal bone varies from individual to individual

- all normal temp. bones have these landmarks

- landmarks must stand in certain relations
5 landmarks

• the exact shape of the temporal bone varies from individual to individual

• all normal temp. bones have these landmarks

• landmarks must stand in certain relations
5 landmarks

- the exact shape of the temporal bone varies from individual to individual
- all normal temp. bones have these landmarks
- in all normal temp. bones have these landmarks must stand in certain relations

slope not too flat and not too steep
Canonical Geometry of the temp. bone = 5 landmarks + geometric relations between them
Canonical Geometry of the temp. bone = 5 landmarks + geometric relations between them

representation of the canonical geometry is
• selective
• incomplete
• qualitative
Canonical Mereo-topology vs. Mereo-geometry
Canonical Mereo-topology vs. Mereo-geometry

Mereo-topology

• *complete*
  all mereo-topological relations between *all* parts (at a given level of granularity)
• qualitative
Canonical Mereo-topology vs. Mereo-geometry

Mereo-topology

• complete
  all mereo-topological relations between all parts (at a given level of granularity)
• qualitative

Mereo-geometry

• selective and incomplete
  some geometric relations between some parts
• qualitative
How to build qualitative representations of canonical anatomical structures?

1. Identify the major parts (Mereology)

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4. Identify landmarks / establish landmark geometry

4. Establish the qualitative order relations using landmarks as frames of reference
5 landmarks → 6 intervals

Rigid does not change shape (bones)
5 landmarks $\rightarrow$ 6 intervals

Rigid does not change shape (bones)
Framed of reference

Rigid does not change shape (bones)

Circle is adjacent-to A
Frames of reference

Rigid does not change shape (bones)

Circle is adjacent-to B
Framed of reference

Rigid does not change shape (bones)

Disc is adjacent-to C and D
Questions:

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Answers

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• How do we **compare** **IMAGES** of individuals with one another and to the canonical ideal?

**qualitative medical image analysis**
Qualitative medical image analysis
Qualitative medical image analysis

Top-down component

• expect
  • certain parts in certain places
  • certain relations between certain parts
Qualitative medical image analysis

Top-down component

- *expect*
  - certain parts in certain places
  - certain relations between certain parts

Bottom-up component

- *extract*
  - features (parts)
  - complete mereotopology/isotropies
  - selective mereo-geometry
Qualitative medical image analysis

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Qualitative medical image analysis

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Bottom-up component
Bottom-up component

geometric abstraction

- completely extract certain invariant properties and relations
Bottom-up component

- **geometric abstraction**
  - *completely extract certain invariant properties and relations*

- **Qualitative landmark-based abstraction**
  - *selectively extract invariants among landmarks*
Bottom-up component

- Geometric abstraction
  - completely extract certain invariant properties and relations

- Qualitative landmark-based abstraction
  - selectively extract invariants among landmarks
bottom-up = extracting invariants

gometry in mathematics = study of properties that remain invariant under groups of transformations
**geometric abstraction**

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construct complete representations
Bottom-up component

- geometric abstraction
  - completely extract certain invariant properties and relations
- Qualitative landmark-based abstraction
  - selectively extract invariants among landmarks
Qualitative landmark-based abstraction

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## Qualitative landmark-based abstraction

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Qualitative landmark-based abstraction

**construct** partial representations

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Conclusions
Ontology
Ontology

Mereology
• How many parts
• What kind of parts
Ontology

Mereology
• How many parts
• What kind of parts
Ontology

Mereology
• How many parts
• What kind of parts

Topology
• Which parts are attached
• Which parts are adjacent
Ontology

Mereology
• How many parts
• What kind of parts

Topology
• Which parts are attached
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Mereology
• How many parts
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Topology
• Which parts are attached
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Ontology

Mereology
• How many parts
• What kind of parts

Topology
• Which parts are attached
• Which parts are adjacent

Qualitative order
• How are things arranged with respect to each other
• How does relative location change during movement
Ontology

Qualitative order
• How are things arranged with respect to each other
• How does relative location change during movement
Ontology

Qualitative order
- How are things arranged with respect to each other
- How does relative location change during movement
Ontology

Qualitative order

- How are things arranged with respect to each other
- How does relative location change during movement

A|B|C|D|E|F

adjacent-to
Ontology

Qualitative order
• How are things arranged with respect to each other
• How does relative location change during movement

A|B|C|D|E|F

adjacent-to

combinatorial ‘space’ of possible relations between landmarks
Qualitative medical image analysis

Top-down component
• expect
  • certain parts in certain places
  • certain relations between certain parts

Bottom-up component
• extract
  • features (parts)
  • complete mereotopology/isotropies
  • selective mereo-geometry

Red arrows indicate the interaction between the two components.