Comparative Analysis of Behavior Using Ontologies

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Motivation

Ontologies and Ethograms

Comparative methods

Social Learning

Florida scrub-jay

Analyzing and Representing Multi-modal Behavior

H. clypeatus - D. Elias

Complex Behavior

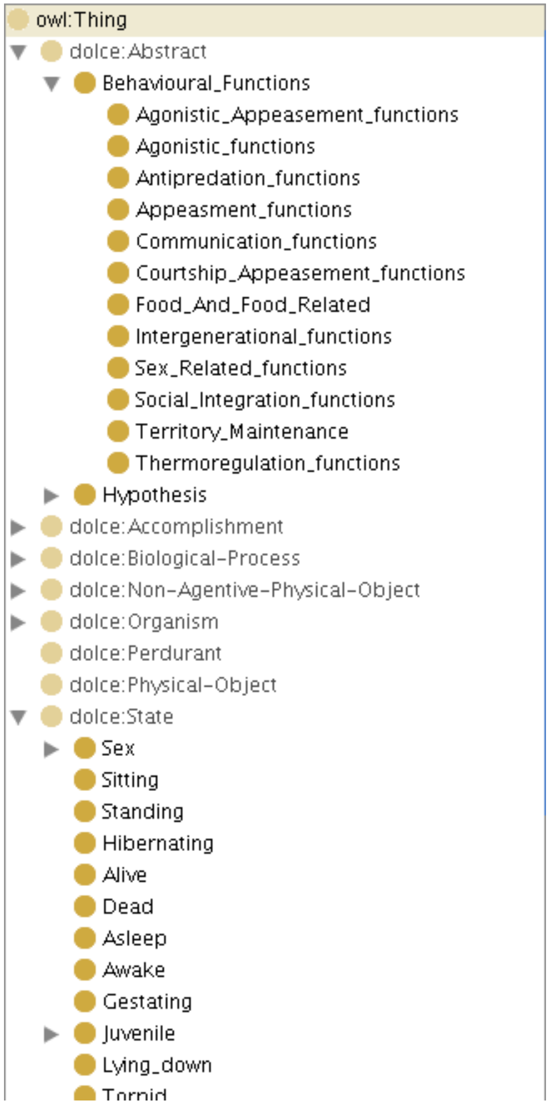
- Characters/Homologies not identified
- Characters of interest
  - Global (e.g., complexity)
  - Context Dependent

Behavior is a process

- Organisms (or their parts) are participants or agents
- Representing time
  - Temporal ordering
    - Overlap
    - Synchronicity
  - Temporal Whole/part relations

Ontologies and Ethograms

SABO

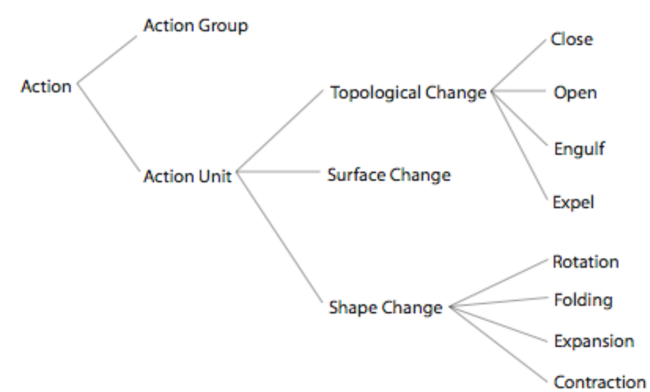


- Developed for categorizing images of behavior
- Implemented in OWL, contains 67 terms
- Tested by annotating video clips of tool use by captive New Caladonian crows and behavior of captive mink and free living rats
- Built on an upper-level ontology of everything (DOLCE-Lite)

http://www.bioimage.org/pub/SABO/SABO_cornell_final.pdf

EKB Upper Level Ontology

- Focus taxonomy of simple actions on topological changes
- Intended to facilitate comparative methods



Midford (2004)

ABO Core

- Model
  - root of ABO_Core
    - Behavioral_Acts
      - Reproductive_Sexual_acts
      - Locomotion
      - Excrete
      - Make_contact_with
      - Produce_light
      - Body_part_movement
        - Move_mouth_parts
        - Inflate_body_part
        - Move_head
        - Other_moved_body_part
        - Move_limb_appendage
      - Produce_sound
      - Secrete
      - Life_history_transitions
      - Color_change
      - Static_pose
        - Sit
        - Stand
        - Lie
        - Hang
      - Produce_electric_field
      - Other_whole_body_movement
      - Group_actions
    - Behavioral_Function
      - Functional_Context
        - Territoriality
        - Maintenance
        - Antipredation
        - Nutrient_acquisition
        - Migration
        - Reproduction
        - Social_integration
      - Tool_preparation
      - Signal_exchange
        - Emission_of_signal
        - Reception_of_signal
      - Play
        - Social_play
        - Motor_development_play
      - Agonism

- Developed at workshops in 2004, 2005
- Current version developed from extensive editing following 2005 workshop
- Current version is a strict taxonomy of 292 terms
- Separate trees for actions and explanatory functions

http://www.ethodata.org

Ethogram

a catalog or table of all the different kinds of behavior or activity observed in an animal.

Groom:

Allogroom: One animal manipulates the fur, extremity, or orifice of another. During a grooming episode, the groomer often looks intently at the portion of the body which is being manipulated. Grooming may include both manual and oral components.

Manual: Individuals use the fingers and whole hand to manipulate and remove materials.

Oral: Use of mouth and lips to manipulate and/or remove materials.

Mutual groom: Same as above, except the two animals groom each other simultaneously.

Allomanipulate: One animal rubs, pats at, or fondles the fur, orifices, or extremities of another (not including genitalia).

Agonistic:

Submissive/avoidance:

Turn away: An animal moves its body so that it is oriented away from another, but does not travel.

Avoid: An animal moves out of the path of an approaching animal or takes a less direct route around that animal.

Hide: An animal removes itself from the view of another. This may occur following an aggressive attack or threat.

Crouch/crawl: This behavior can take two forms: 1) An animal bends all four limbs, presses its ventrum to the ground, and may try to travel while in this position; or 2) the animal may crouch while in one of the sitting positions by lowering the head, hunching the shoulders, and often covering the head with an arm.

Present: May take two forms. One form is similar to a sexual present, but is much briefer. It may be accompanied by a series of brief glances directed towards the presentee. An animal may also "offer-up" or present an arm to the presentee. (specify act)

Run away: An animal moves rapidly (with a running gait) away from another.

Excerpted from: “Collection of Gorilla Ethograms, compiled by: The Gorilla Behavior Advisory Group [affiliated with the Gorilla SSP]
Jackie Ogden, Zoo Atlanta and Georgia Institute of Technology, Deborah Schildkraut, Ph.D., Boston MetroParks Zoos Co-chairs

Ontology as Ethogram

- Terms with definitions and computable relationships
- Other attempts to formalize ‘ethograms’
  - EW Movement notation (Golani 1976,1978)
  - “Standard Ethogram” (Schleidt et al. 1984)

Loggerhead (*Caretta caretta*) nesting

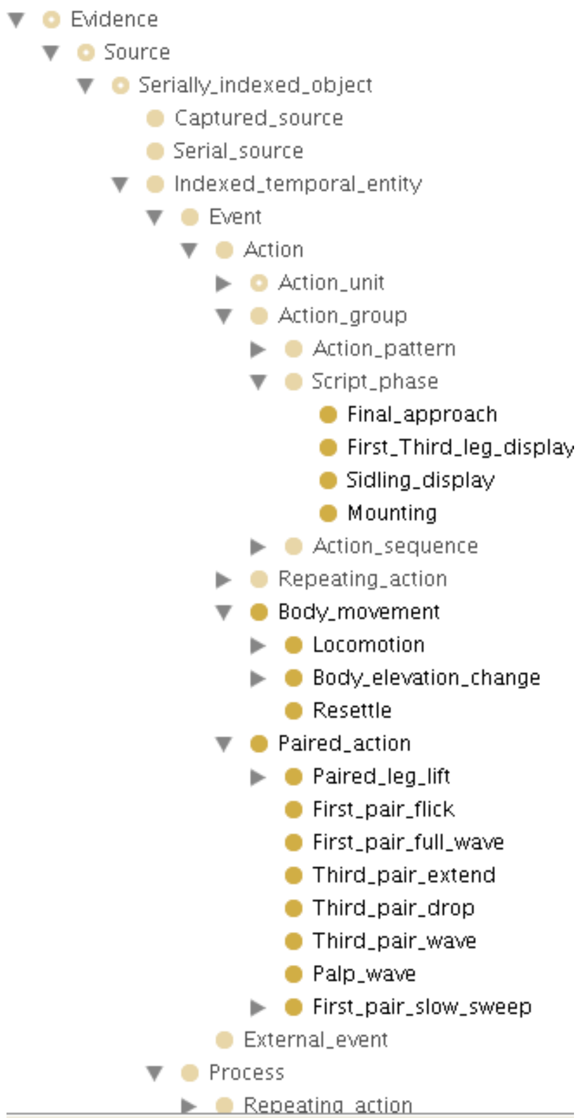
- EKB_thing
  - Location
  - Tangible
    - Physical_object
    - Stuff
  - Intangible
    - Process
      - Event
        - Action
          - Action_group
            - Action_Pattern
            - Script_phase
              - Approach_beach
              - Ascend_beach
              - Wander_over_beach
              - Make_body_pit
              - Dig_egg_chamber
              - Lay_eggs
              - Fill_and_pack_chamber
              - Cover_body_pit
              - Return_to_surf
              - Depart_from_beach
              - Return_on_same_track
              - Initial_sand-flicking
            - Action_sequence
              - Simple_script
                - Loggerhead_nesting_sequence
          - Action_unit
            - Topological_change
              - Close
              - Engulf
              - Expel
              - Open
            - Shape_change

- Built with Protégé
- 321 Terms
- 41 Relations


Jack P. Hailman

http://mesquiteproject.org/ontology/

Habronattus courtship



- Built directly from video clips of seven species using Protégé and iMovie
- Currently two complete (*H. californicus*, *H. clypeatus*) and one partial (*H. formosus*)
- H. californicus ontology has 140 terms and 35 relations

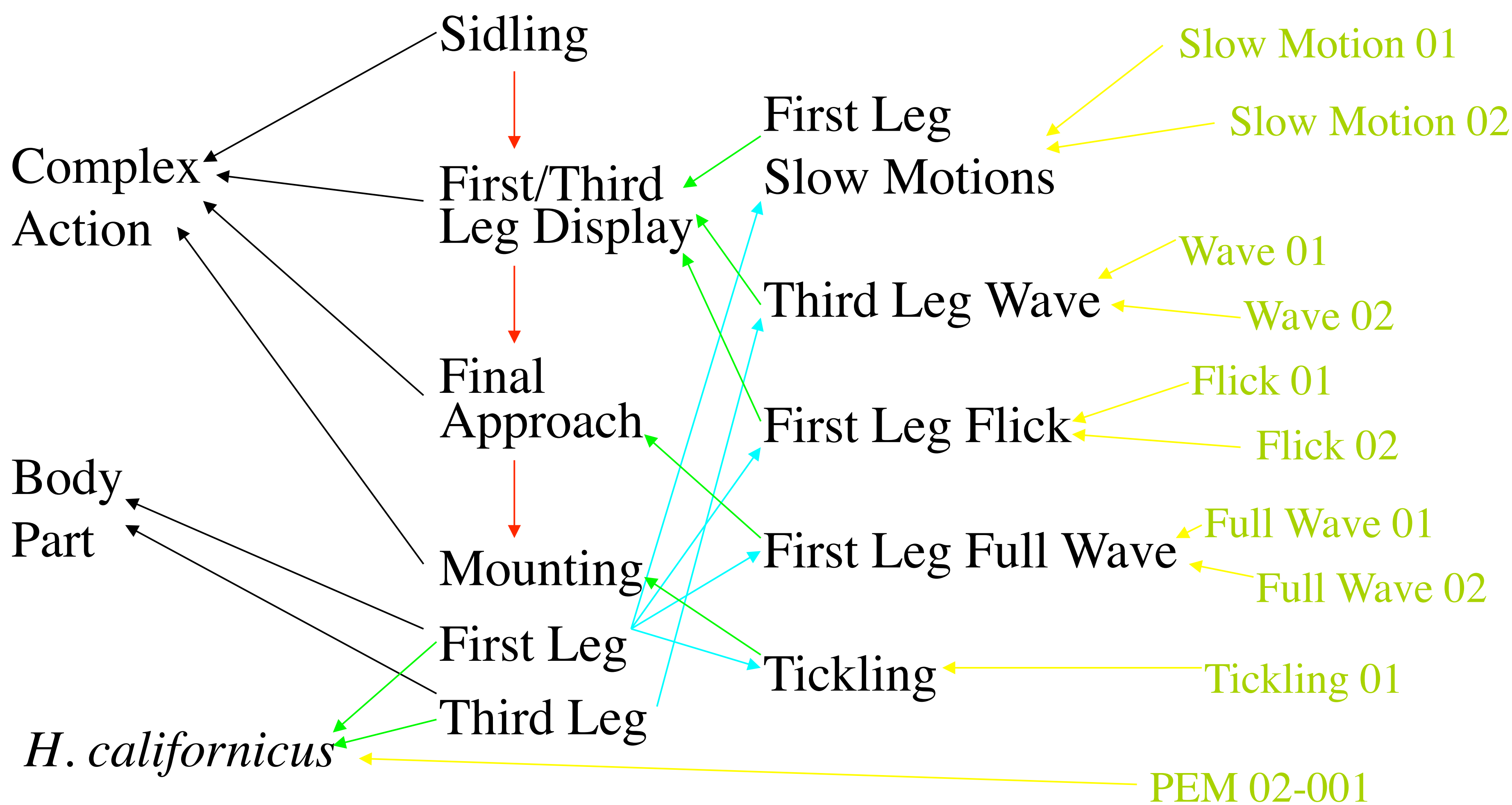
http://mesquiteproject.org/ontology/

Other taxa-specific behavior ontologies

- Bowerbird courtship
  - Scholes (2006, 2008)
- Social Insect Behavior
  - Smith (2007)

Schematic Ontology of *Habronattus* courtship

A set of terms+taxonomy+whole/part+other relations+individuals



Ethosearch - an Ethogram Database

- Outgrowth of Ethogram.com
- Currently soliciting ethograms for inclusion
- Web portal has been prototyped

How Ethosearch Works

- Text-based descriptions are attached to a standard hierarchy (ABOCore)
- Allows user to see descriptions of the same behavior in the same species side-by-side
- Effort also includes updating and adding text definitions to ABOCore
- Will support on-line submission
  - Quality of submission issues

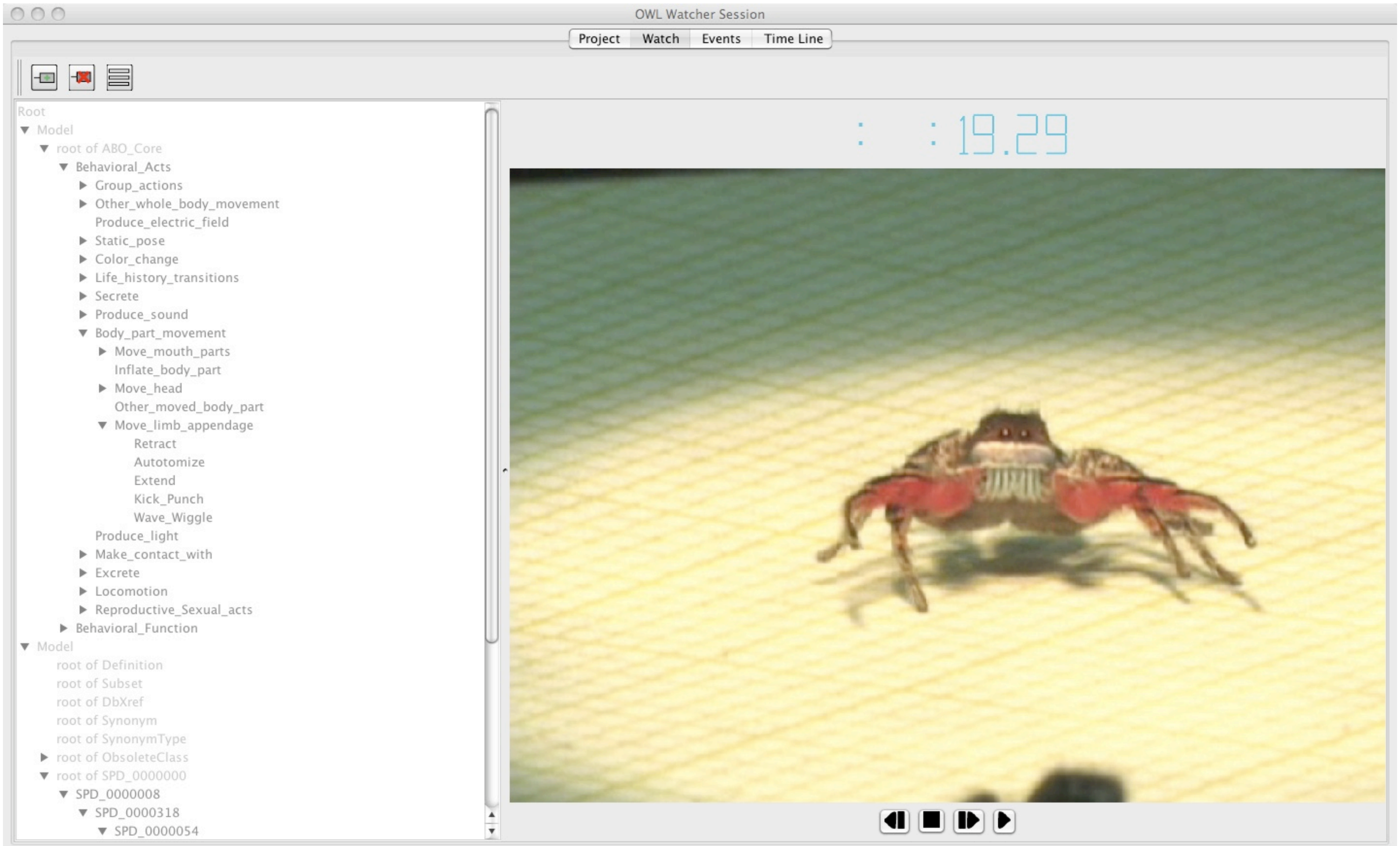
Ethogram

Ontology

Ethogram

Ontology

Database of
Individual(s):
Events and organisms


OWL Watcher Session
Project
Watch
Events
Time Line
: : 19.29
Root
Model
root of ABO_Core
Behavioral_Acts
Group_actions
Other_whole_body_movement
Produce_electric_field
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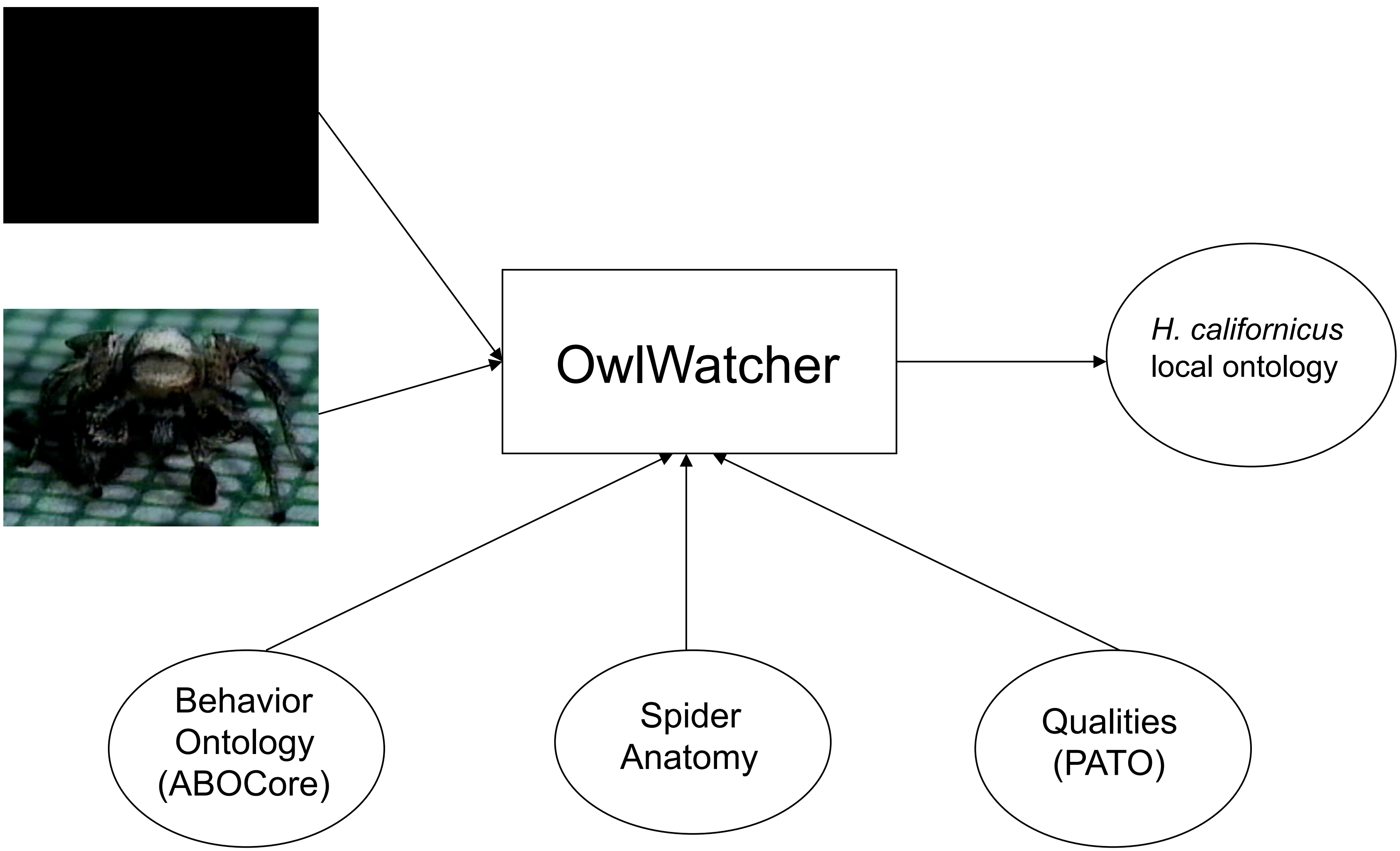
Move_head
Other_moved_body_part
Move_limb_appendage
Retract
Autotomize
Extend
Kick_Punch
Wave_Wiggle
Produce_light
Make_contact_with
Excrete
Locomotion
Reproductive_Sexual_acts
Behavioral_Function
Model
root of Definition
root of Subset
root of DbXref
root of Synonym
root of SynonymType
root of ObsoleteClass
root of SPD_0000000
SPD_0000008
SPD_0000318
SPD_0000054

OwlWatcher

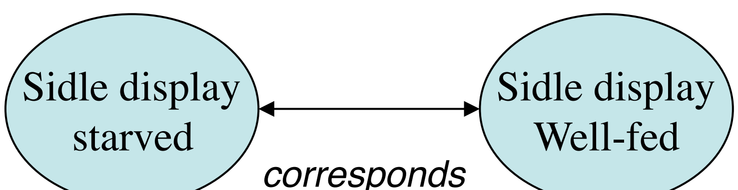
- Combines Video Playback with Ontology construction
- Ontology is dependent on other ontologies, but is a separate entity
- Ontology terms used to annotate behavior events, which are individuals
- Captures descriptions - prior to characters


OwlWatcher
H. californicus local ontology
Behavior Ontology (ABOCore)
Spider Anatomy
Qualities (PATO)

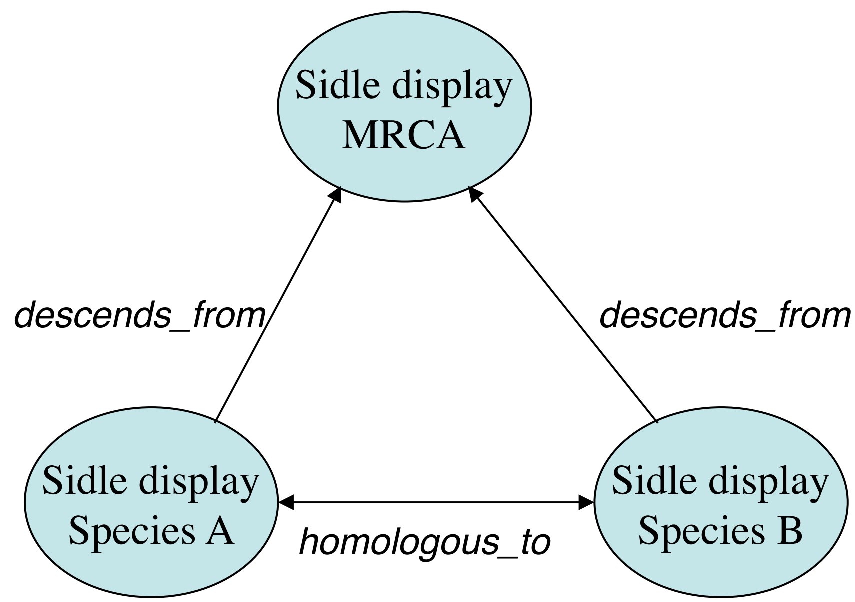
Comparative Methods

- Alignment
  - Without trees (similarities)
  - With trees (homologies)
- Scoring
  - Extract to matrix
  - Ontology-based methods
    - Counting (ontology parsimony)
    - Model-based methods

Alignment



Sidle display starved
Sidle display Well-fed
corresponds



Sidle display MRCA
descends_from
descends_from
Sidle display Species A
Sidle display Species B
homologous_to

Non-tree Alignment Tools

- Tools for comparing and merging ontologies already exist
  - Prompt: a tool for merging and comparing ontologies in Protégé (general ontologies may be harder than comparing phenotypes of closely related species)
  - COBrA: an OBO-based tool for editing/comparing pairs of ontologies (http://www.xspan.org/cobra/index.html)
- These tools produce lists of corresponding (aligned) terms

Approaches to tree-based alignment

- Simple shared ontology ('Uberon')
- One ontology per species
- Tree differences -> ontology modification

- Any of these methods can use homology information from
  - Explicit assertions
  - Inference from other information (e.g., lexical similarity of term names)

Simple shared ontology (‘Uberon’)

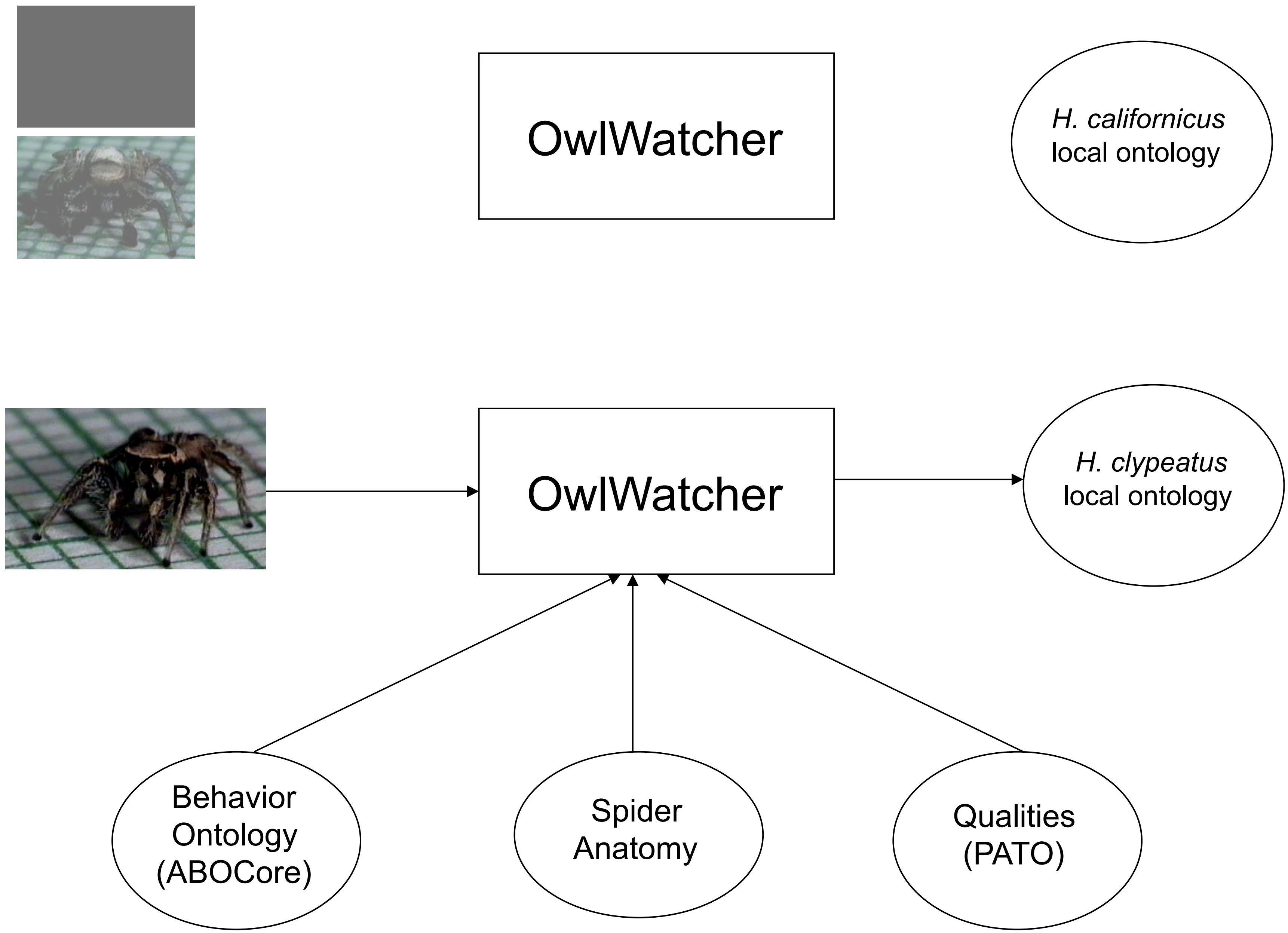
- Simple, ‘non-controversial’ tree
  - Textbook level tree relating model organisms
- Allows construction of shared ontology by hand
- Not easy to change tree

One ontology per species

- Requires computationally expensive merge
  - *n* ontologies
  - Phylogeny for *n* species
- Computationally intensive, but may be tractable for small trees
- Changing the tree, or multiple trees requires making a new merge

Conversion using alternative tree

- Procedure
  - Construct a shared ontology for one well resolved tree (base tree)
  - Compare alternative tree to base tree
  - Modify ontology to reflect the differences in the trees
- Not necessarily possible or easier than merging individual ontologies


OwlWatcher
H. californicus
local ontology
OwlWatcher
H. clypeatus
local ontology
Behavior
Ontology
(ABOCore)
Spider
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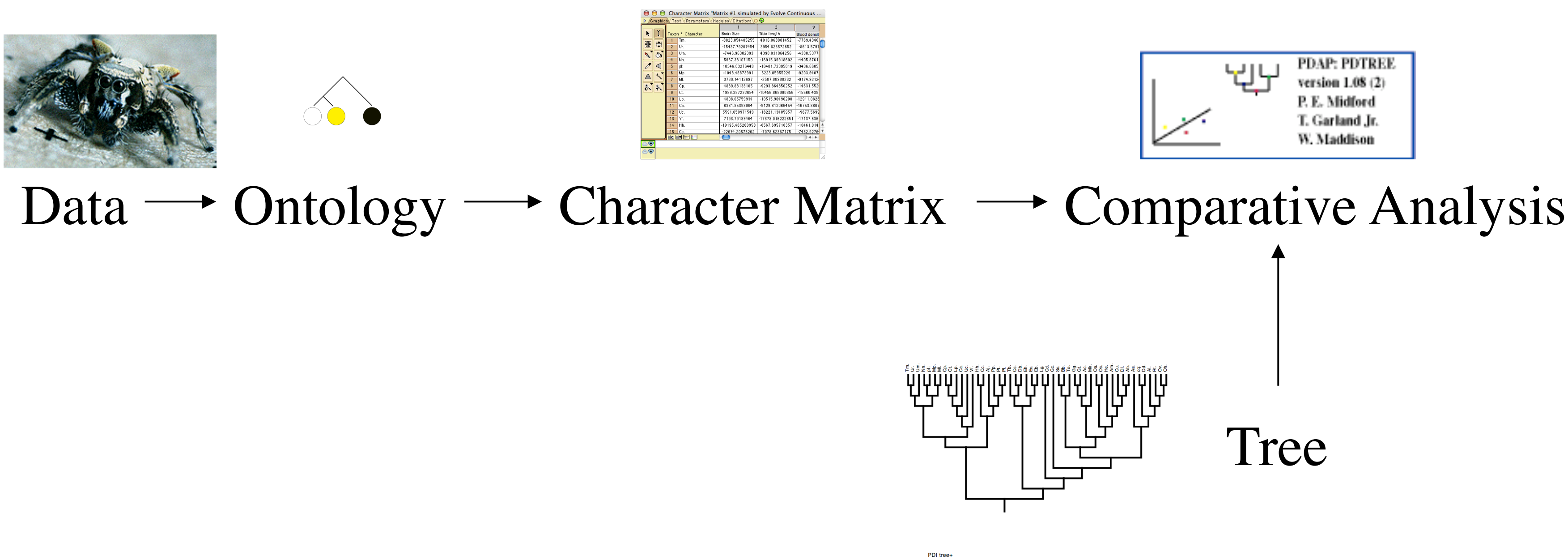
Qualities
(PATO)

Comparative Methods for Ontologies

1. Extract ontology to data matrix, proceed as usual
2. Compare ontologies directly
    1. Model-free methods
    2. Model-based methods

Extract Ontology to Data Matrix



Extract Ontology to Data Matrix

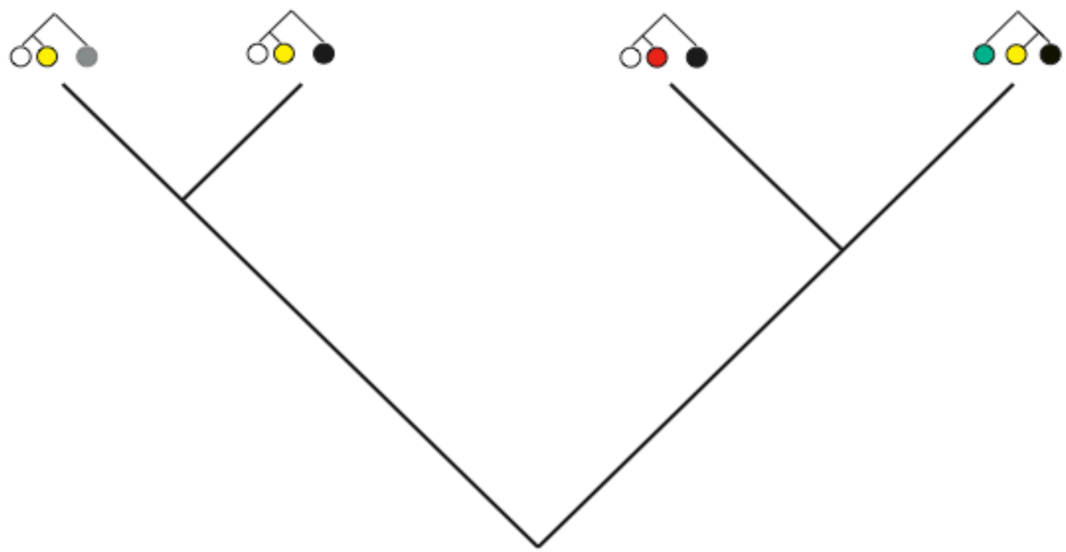
Advantages

- Straightforward
- Minimizes homology issues

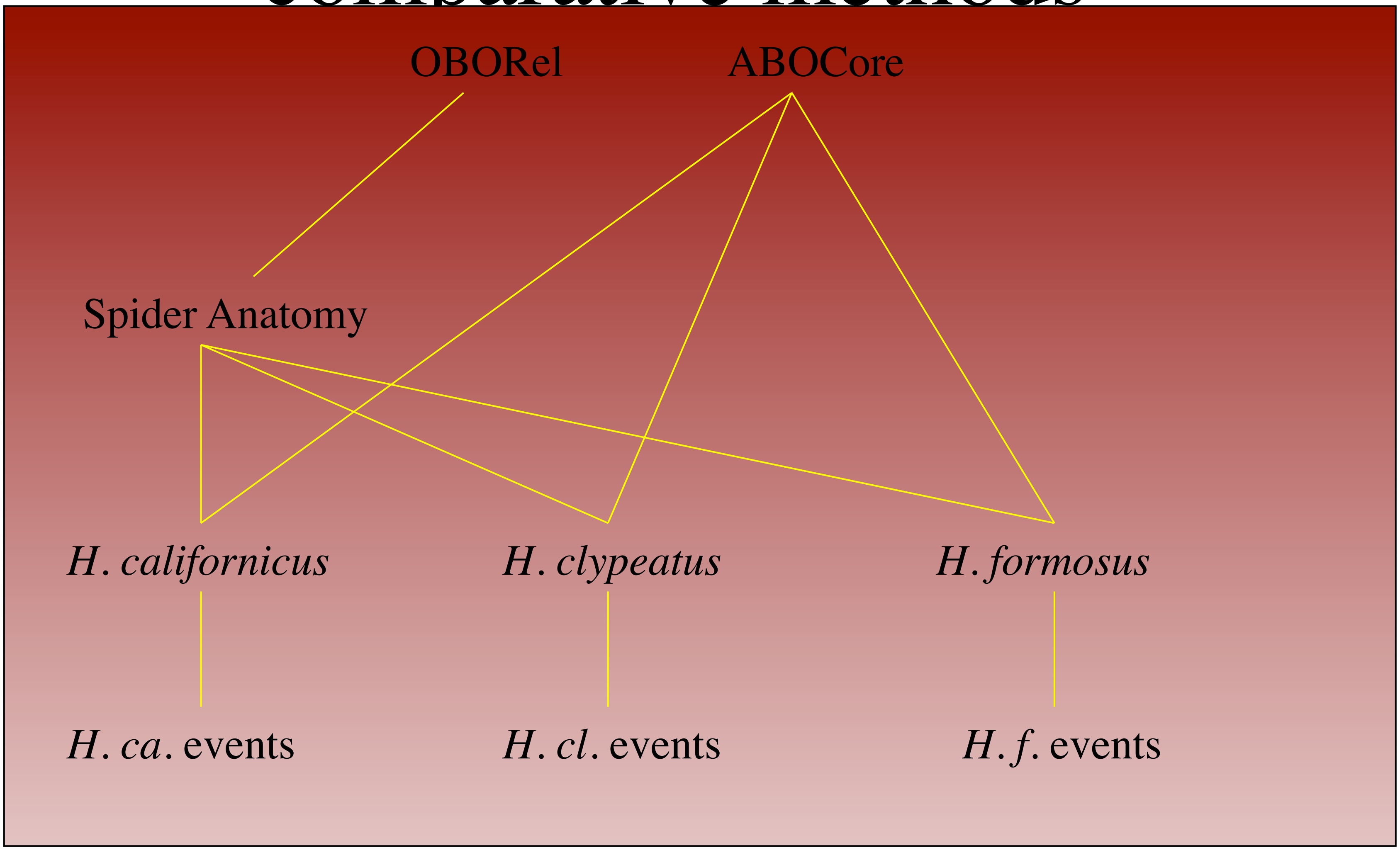
Disadvantages

- Ignores the structure in the ontology
- Hides assumptions of character homology and independence

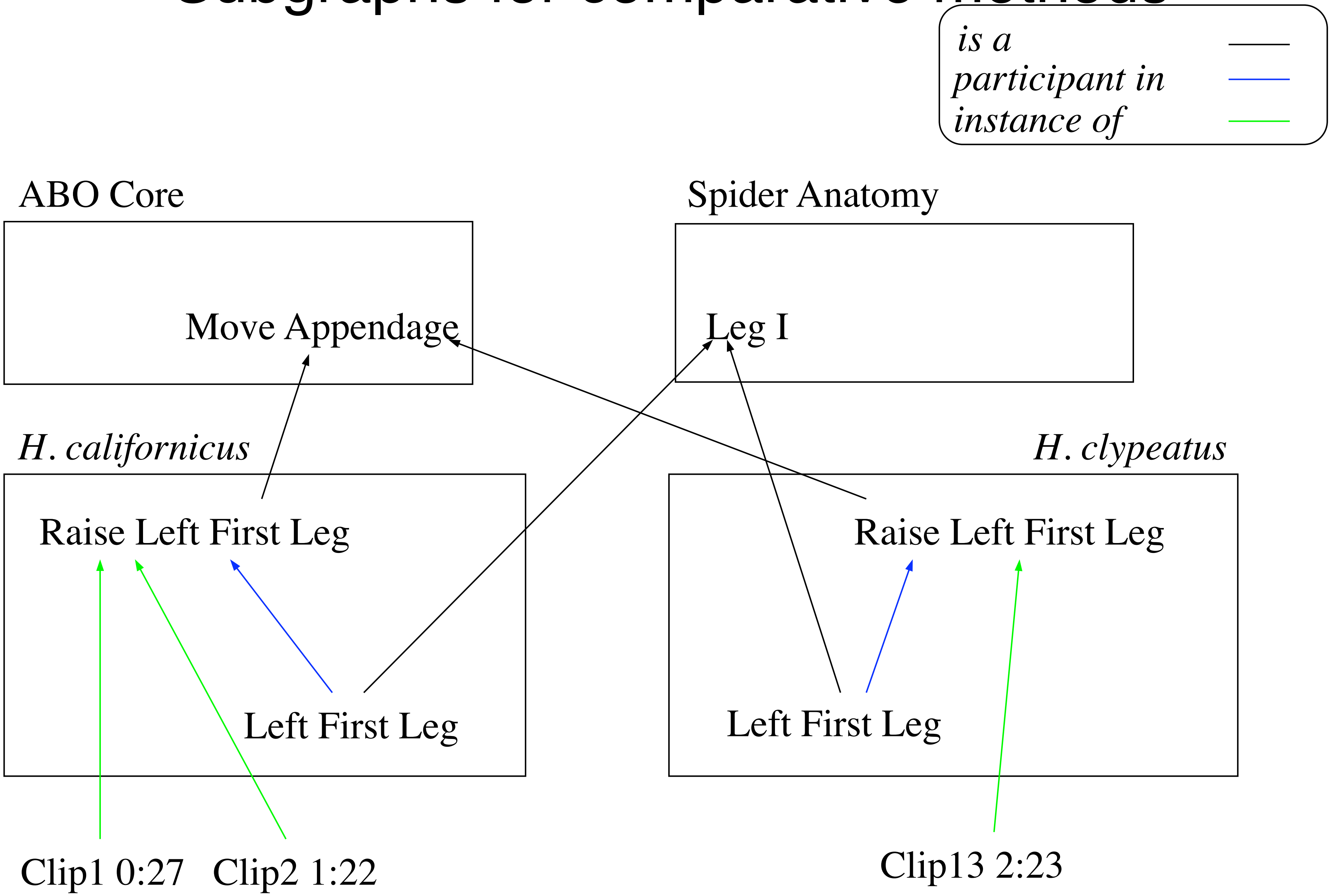
Can we compare subgraphs within ontologies directly?



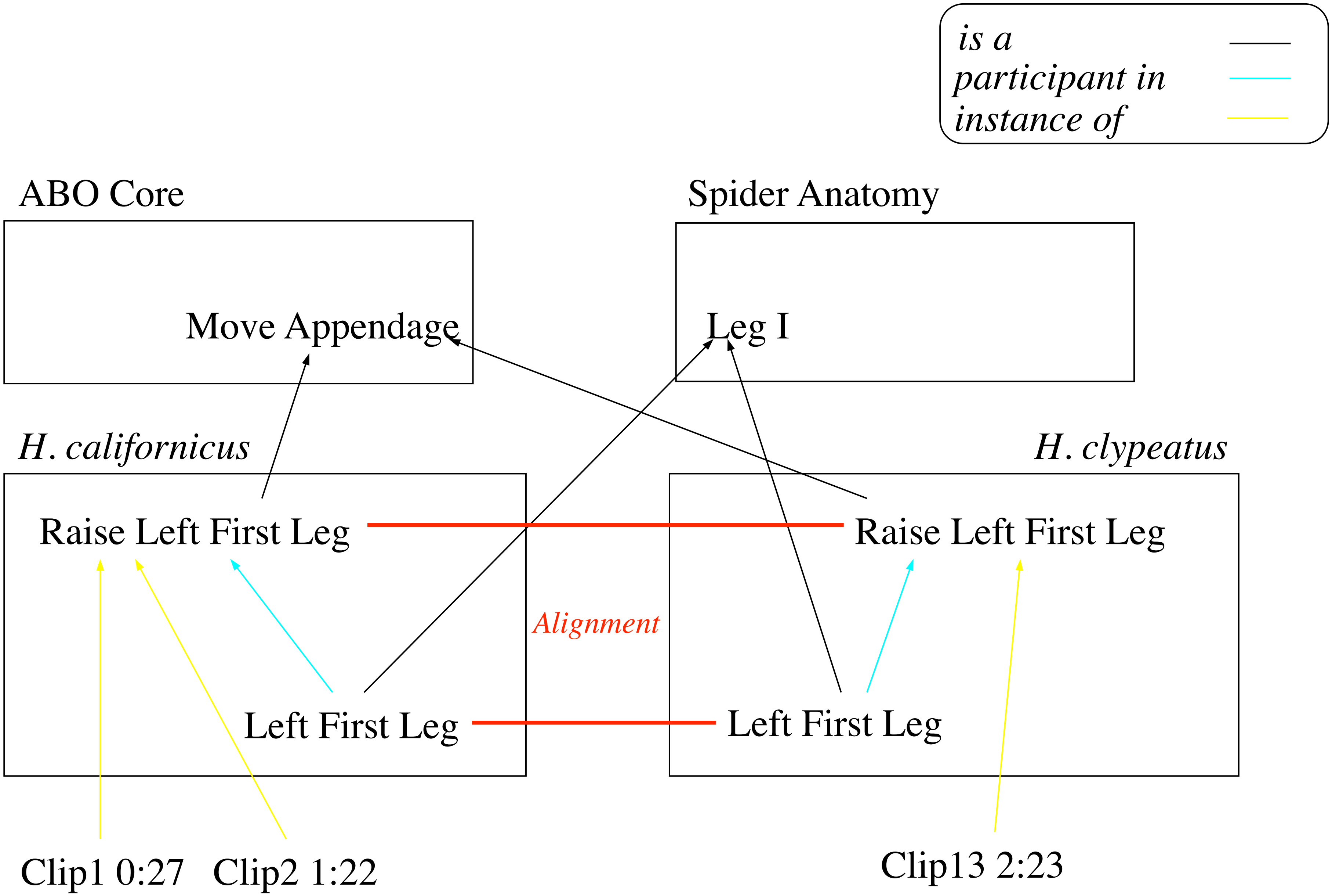
Structuring ontologies for comparative methods



Subgraphs for comparative methods



Subgraphs for comparative methods

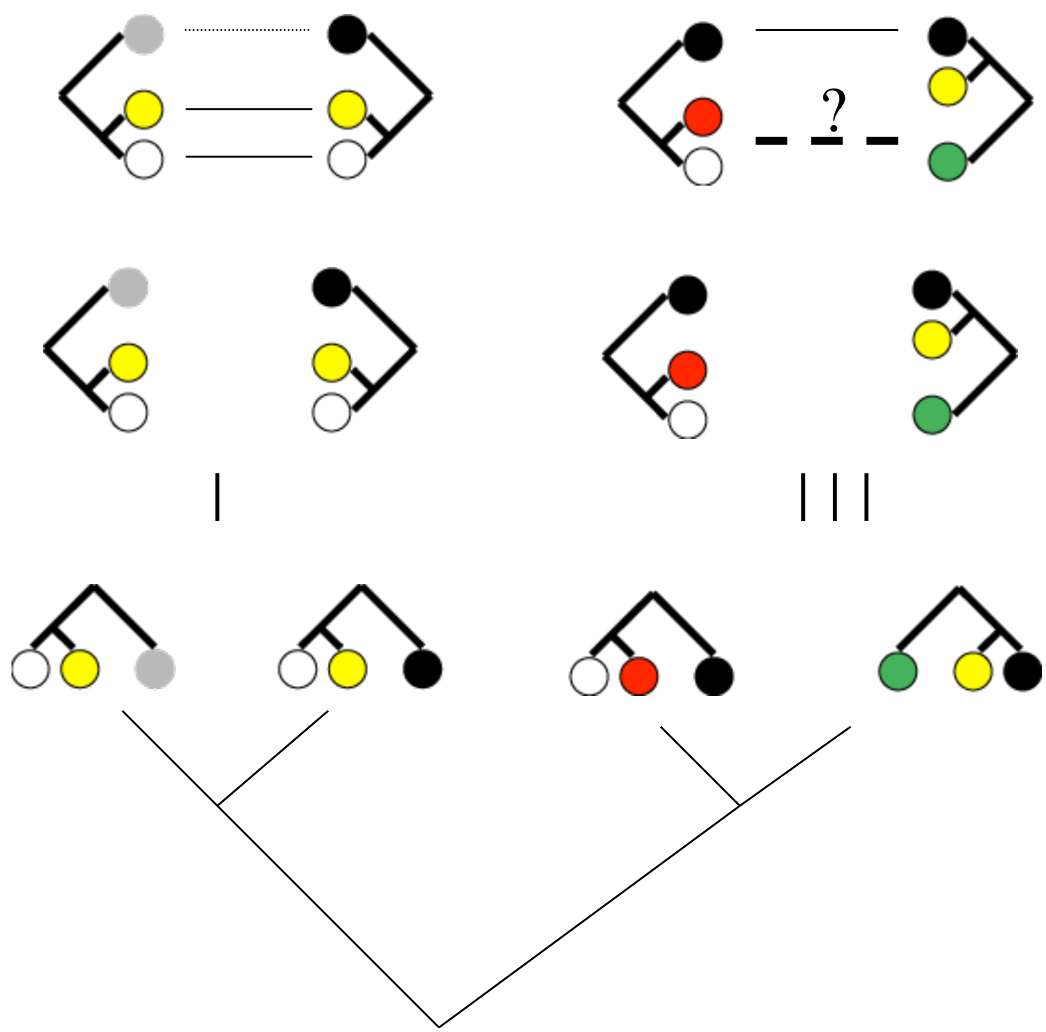


Compare and Count differences

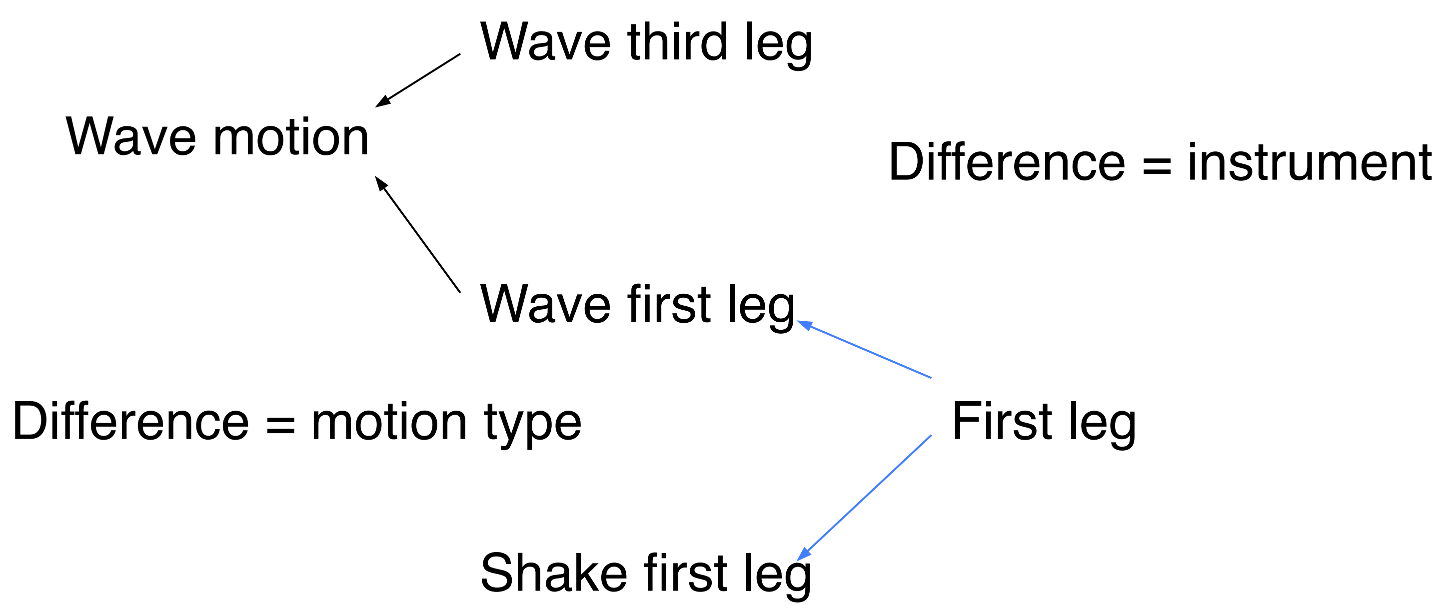
Align

Count

Trace History
On Tree
(and check
plausibility
at each node)



Counting differences



Count differences, possibly weighed by semantic distance between differing concepts

Model-based methods

- Upper ontologies can provide terms for building models
- Model itself might be reversible
  - Insert contiguous subsequence
  - Delete contiguous portion of sequence
  - Reversibly modify an individual element
- But changes proposed by model may have consequences…
  - Propagated changes through a portion of the ontology
  - Constraints rejecting a modified subgraph that represents an impossible situation

Acknowledgements

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- Sue Margulis

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Approach to comparative questions

- Focus on relatively small number of related species
- Use base ontologies of behavior and anatomy and build separate ontologies (= ethograms) for each species
- Comparative methods built on process of merging and aligning these ontologies

Traditional comparative approaches to behavior

- Simple discrete or continuous variables
  - Martins (1996)
- Correlation methods
  - Pagel (1994)
  - Independent contrasts

Model of complex behavior

- Behavior should be broken down as sequences of partially ordered events
  - At the instance level, always represented as sequence
- At the class level, sequences might be represented directly, or using a ‘Markov’ formalism

Molecular and Behavioral Sequences

- Long sequences
- Small number of types (e.g., 4 or 21)
- Elements in the sequence have no (relevant) parts or subsequences

- Short sequences
- No fixed limit to number of types
- Elements in the sequence frequently have parts or subsequences

Alignment

Molecular Sequence

- Identify homologies by position
- Small, fixed vocabulary virtually eliminates need for similarity metric
- Generally phylogenetic

Behavior Sequence

- Identify homologies by semantic similarity and position
- Events may expand into their own subsequences
- Not necessarily phylogenetic

What about using ontologies to compare structured characters?

What about using ontologies
to compare structured characters?

Like sequences of behavior?

Questions

- Where do sequences differ?
- Which positions show the greatest diversity?
- Do positions vary differently in different lineages?
- Do sequences differ in global measures of complexity?
- What is the best model of sequence change?

Alignment with Trees

- Assigning homologies
  - Human assertions
  - Machine inferences
    - Name matching
    - Name matching plus similar pattern of relations
- Assessing reliability

Questions

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- Which positions show the greatest diversity?
- Do positions vary differently in different lineages?
- Do sequences differ in global measures of complexity?
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Complex Behavior - Challenges

- Where is the variation in complex behavior?
- Identifying homologies
- Are there dependencies
  - Among elements in a complex behavior pattern?
  - In the larger context of the behavior?
- What about variation in ‘global measures’
  - Complexity of homologous patterns
  - Correlation with
    - Brain size?
    - Complexity of other behavior patterns?

Applications for comparative methods for complex behavior

- Phylogenetic
- Genetic
- Cultural
- Other Ecological

Extending Ontologies

- Can index and structure observations of individual behavior events
- Can be compared across species
  - Identify homologies
  - Capture 'non-atomic' attributes of behavior
    - E.g., Addition/deletion/reordering of behavior sequences