Microtheories

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Abstract:
In this paper, we argue that contexts of reasoning are highly relevant to the type of research the Humanities do. We describe the use of contexts in textual analysis. We also discuss some practical considerations in using one implementation of contexts: microtheories in the CYC Project. We conclude that support for contexts is an indispensable part of the ontological toolkit for research in the Humanities.
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1 Introduction

Logical inference can conclude arbitrary facts from a knowledge base that contains both P and ¬P. While this will rarely happen in a well-designed expert system, the opposite is the case when multiple points of view – for example when combining independently designed expert systems – come into play. This problem is the so-called *Generality* (of AI) problem; its description is commonly ascribed to John McCarthy (McCarthy, 1987). McCarthy also proposed a solution: Associating the different points of view with logical contexts. Basically, logical contexts allow for having both P and ¬P available, though not at the same moment, during reasoning.[1] Each context has to be locally consistent, but all contexts taken together need not be (global consistency). This theory of contexts was worked out during the late 80s and early 90s by McCarthy's colleagues and students (in the broad sense of the term).[2]
One of the earliest implementations of contexts was in Doug Lenat's CYC Project, where contexts were called *microtheories*. Given its goal of formalizing common sense, which is not an expert theory, the CYC Project could not expect to achieve global consistency – esp. in a knowledge base containing millions of facts – and therefore aims for local consistency instead.
It is precisely this situation of manipulating contradictory viewpoints that the Humanities find themselves in. This makes the ontologically interested Humanities researchers prime candidates for the use of microtheories. Consequently we will first discuss how to profitably apply microtheories to the research problems of the Humanities before we describe some practical considerations of working with microtheories in CYC.

2 Applying Microtheories to Research in the Humanities

The Humanities are replete with situations where divergent facts must be manipulated together. This is due to their emphasis on working from opinionated knowledge such as source documents or prior research. Observe that the illustrative examples we provide in the following discussion are at the introductory level of hermeneutic competency. These are some of the techniques that ground the Humanities as a discipline: managing multiple

[1] It is important to note that microtheories are not equivalent to a mere disjunction of facts. Two key differences are: The disjunction of both P and ¬P is simply a tautology and inferentially infertile. Furthermore, there is no way to distinguish the origins of the facts, a service that microtheories as meta-statements about the facts can provide. Microtheories model sets of possible worlds the follow necessarily from what was said by specific voices in the discourse.
[2] (Lenat, 1987), (Guha 1991), (Buvač , 1995) (cf. there for additional references).

points of view, multiple readings, multiple interpretations, temporal progression and unshared assumptions.[3]

Managing Multiple Points of View

The classical situation of multiple points of view is one where the source documents express multiple and conflicting versions of an event.[4] Consider the conflicting descriptions from the Norse *Edda* regarding the death of Sigurd:[5]

> Sigurd was slain // south of the Rhine [in the forest]
> up in a tree // a raven cried …
> – *Fragment of Sigurd Lay*
> The hero [Sigurd] avenged himself // there in the hall [in Worms]–
> the reckless youth [Guthorm] was killed in return …
> – *Short Lay of Sigurd*
> But the saddest moment // was when my Sigurd
> lord of battles // was slain in bed
> – *Gudrun's Chain of Woes*

Any ontological representation that models the contents of these lays has to come to terms with the fact that Sigurd cannot die in three places. However, by assigning these representations to three separate microtheories – one for the *Fragment*, the *Short Lay* and *Gudrun's Chain of Woes* respectively – the representations can co-exist.[6] In some sense, microtheories are like having several sub-ontologies available at once.

Managing Multiple Readings

The divergent points of view need not be anything as spectacular as offering incommensurate narratives for the same event. Often they are rather prosaic differences in the documentary evidence, such as textual variants. Here, manuscript-specific microtheories can provide the same level of support a text-critical apparatus can provide in a critical edition.

For example, Goethe – in describing his family's new house in Frankfurt (*Dichtung und Wahrheit*, I, 27) – calls the antechambers "funny" (lustig), which has prompted Boucke and Beutler, two Goethe researchers, to propose "airily" (luftig) as a correction. The text-critical editor of the Hamburg edition, in reviewing these three "sources", did not follow the emendation suggestion.

This situation could be modeled adequately with four microtheories – one for Goethe's prints, one for Boucke and one for Beutler (who presumably do not agree in some of their other correction suggestions and therefore deserve separate contexts), and one for the Hamburg edition, which in this situation could simply inherit the textual contents of that phrase from the Goethe microtheory via subsumption.

Managing Multiple Interpretations

An equally common situation is the dialogue with the existing literature on a topic such as the lays of the *Edda*. Here, microtheories can contextualize the different interpretation possibilities that other researchers have proposed. The structure of microtheories as a subsumption lattice lends itself quite well to modeling the influence of scholars and the formation of "schools of thought;" microtheories representing influenced or dependent scholars simply derive part of their contents from the microtheories modeling the influential stance.

Finally, two special cases of the multiplicity of interpretations are worth mentioning. The first instance is the process of tradition-critical investigation, where some of the sources

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[3] For a detailed example that exhibits several of these properties, see the appendix.
[4] See also (Belasco et. al., 2004).
[5] All translations are from (Terry, 1996).
[6] This of course assumes that the individual lays are internally logically consistent; if they are not, then additional microtheory work will be necessary to maintain maximal local consistency.

themselves are interpreting their predecessors. Consider the fate of Gudrun in the lays of the *Edda*. In the *Short Lay of Sigurd*, Gudrun marries Atli and moves to the land of the Huns, while in the *Grief of Gudrun*, she goes to stay with Princess Thora in Denmark. Those responsible for the *2nd Lay of Gudrun* apparently were aware of both of these traditions, for they harmonized them: Here Gudrun first goes to Princess Thora and is then recalled by Queen Grimhild to marry Atli.
A very different case of the multiplicity of interpretations is the changing thinking of the individual researchers themselves, i.e. their mental walk through the iterations of the "hermeneutic circle"[7] of interpretation.

Managing Temporal Progression

As the example of the modeling of a researcher's changing thinking indicates, microtheories can also be used to model temporal progression.[8] For example, the microtheories that modeled the different publications of a researcher could be indexed by the year of the Gregorian calendar in which they were published.
Temporal progression is also relevant to appropriately model the propositional attitudes of the entities described in the sources as these change over time. Consider for example how Gudrun's brothers become weary of Sigurd or the ways in which Gudrun exacts vengeance on her own family. However, here the temporal index is no longer congruent with the Gregorian calendar; rather, it is "story time" that is being modeled here. Since "story time" is such a source-dependent construct and temporal information is often very sparse, it is difficult to give general suggestions on how to best model this source-internal timeline.

Managing Unshared Assumptions

Finally, microtheories can be used to segregate assumptions of the sources that the reconstructing researcher cannot share. Consider the ordeal by boiling water that Gudrun and Atli's former mistress Herkia undergo when Herkia wrongfully accuses Gudrun of infidelity (*Third Lay of Gudrun*). To the original audience of the lays, it was clear that the person with Truth on their side would not be hurt by a straight-forward physical event (in this case, heat transfer), while the person with Truth against her could not but take damage.
While such an understanding is an important part of the ontological model of the time of the source, it is not convenient to have that knowledge present and "active", so to speak, at all times during the reconstructive process. By delegating such "moralistic" extensions of everyday physics to a separate microtheory, the exceptional can be treated as an exception and quarantined until needed.

Dealing correctly with Beliefs and other Modals

So far the pretension has been that the contents of the microtheories were statements about the way possible worlds are. However, that is merely a useful simplification. More precisely, microtheories contain statements about how the worlds are which are completely determined by the contents of the microtheory (and its generalizations). The main issue here is that within a microtheory, all the standard rules of first- and higher-order logical inference hold. But statements of belief, desire, interpretation, etc. are modal and not subject to the standard rules of first- and higher-order logical inference; people need not (and often do not) believe what follows logically from their believes. So, in order to perform standard inference within the reconstructed mental models of sources and colleagues, a microtheory representation of their arguments and beliefs has

[7] Hans Georg Gadamer, *Wahrheit und Methode*, Mohr – Siebeck, [6]1990.
[8] Indeed, (Lenat, 1999) has proposed that contexts describe a multi-dimensional space, in which time is merely one index of interest among many others.

to be available. At the same time, a modal representation is needed, because their beliefs, wishes and desires are modal.
Microtheories actually allow handling this situation correctly, at the cost of some overhead. We employ two microtheories instead of one – the first for the modal statements, and second for housing the projection of those worlds that follow deterministically from the modal statements. In the projection microtheory, the rules of regular inference hold. Here, what follows from the beliefs is true, regardless of whether the modal actor believes these consequences. However, the modal sibling microtheory allows distinguishing which statements in the projection microtheory correspond to one or more stated beliefs, and which statements are the deductive consequences of a stated belief (and therefore need not be shared by the modal actor).
Using this setup is it now possible to reason effectively about contradictions or unintended consequences of the modeled theory. Any sentence that is true in the projection Mt but cannot be tied back to a modal statement is a potential candidate for an unintended consequence. And any sentence that is true in the projection Mt but explicitly negated in the modal statement Mt is an indication of a contradiction between what the authors say and what the authors imply.

3 Some Practical Considerations

In the following, we discuss how to exploit these opportunities for interesting ontological modeling using microtheories in practice in a system like CYC that implements most of the above discussed operations.[9]

Designing Microtheory Hierarchies

Microtheories are organized in subsumption lattices, with more specific microtheories inheriting from more general ones. Inheritance works like whole-sale inclusion; every fact or rule present in the more general microtheory is available in the more specific client microtheories.
In general, any microtheory should only contain as much information as absolutely necessary. Facts that one or more microtheories might want to share are best factored out into their own microtheory. For example, if of the three lays of Sigurd one did not know about the character of Guthrom, it might be best to keep the information about Guthrom in a separate microtheory to be included only in those lays that have the character.

The Shape of Microtheory Hierarchies

While microtheory hierarchies are typically tree-like in shape, there is no apriori reason they need to form a tree. However, cases such as a diamond-shaped directed acyclic graph or even a loop have semantics that are often unintentional. It is therefore worth considering the implication.
A diamond-shaped directed acyclic microtheory hierarchy means that the terminal (often so-called "collector") microtheory holds the union of all beliefs. In the case of the disagreement over Sigurd's place of death, this would be a meaningless operation, for that microtheory would be self-inconsistent and therefore could infer arbitrary facts.
A microtheory graph loop has the semantics of an equivalence class: the set of microtheories involved in the loop form one large microtheory, again containing the union of all the beliefs.
This is not to say that these idioms have no valid uses (otherwise, it would be preferable to suppress them). "Collector" microtheories are most useful when there are several points of view to be modeled, and most of the points of view agree about most but not all

[9] For a recent description of how CYC's inference works in general, see (Ramachandran, Reagan, Goolsbey 2005) – though this is not the primary focus of that publication.

of the facts. In terms of microtheory hierarchy shape, these cases cash out as a large number of more general "sibling" microtheories.
The only valid uses of microtheory loops that we are aware of at this point in time involve either definitional and bootstrapping issues in the upper ontology or the explicit intention of stating that two theories (e.g., in mathematics) are in fact equivalent to each other.

Reasoning with Microtheories

In CYC, the interpretation of every fact and every inference is localized to a specific region of context space. All conclusions that the inference draws involve only facts that are visible from that region of context space, that is, are stated either in the leaf microtheory or one of its generalization microtheories.
While microtheories are "reified", that is, first-order objects, in CYC, reasoning with microtheories is not restricted to those sub-regions of context space that have been so reified. CYC's language contains several functors that allow the constructive specification of regions of context space, e.g. by forming the union of microtheories. The inference works as if a microtheory had been reified that was a specialization of all the microtheories being combined together and is a classic example of a valid use of a "collector" microtheory.

Reasoning into Microtheories

One question that we have not addressed is how to leverage the contradictory knowledge that has been so carefully segregated into separate microtheories. While it is already helpful to have the contradictory pieces of information represented together while preserving the power of logical inference, CYC provides for a specific way in which the contradictory knowledge can be carefully employed in inference.
CYC supports a special logical operator called `ist`, best understood as "is true (in region of context space)", which takes as its arguments a region of context space and a conjunction of sentences. During logical inference, each `ist` inference is handled independently of the others, thereby preserving the specific point of view.[10] This effectively compartmentalizes the reasoning steps, so that each inference can execute in a consistent view of the knowledge. Humanities researchers perform such inferences all the time, e.g. "Compare and contrast the description of the death of Sigurd in the *Short Lay of Sigurd* with the description in the *Chain of Gudrun's Woes*."

Future Research Directions

Much work remains to be done in the implementation of microtheories. In addition, only one of the additional dimensions of context space hitherto identified – namely time – has been tackled so far.
Most notable for the discussion here is the fact that in the current implementation of CYC, it is not possible to block individual facts from being inherited if a microtheory is declared to be a specialization of another.[11] This has the somewhat counter-intuitive result that, if a microtheory wants to inherit only part of another microtheory's contents, the more general microtheory has to be re-factored into the interesting part and the remainder.

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[10] This capability follows from the property of *contextual omniscience* of the theory of contexts, which means that all microtheories can introspect into all the other microtheories; cf. (Buvač 1995) and (Buvač et. al. 1995).
[11] This may be a consequence of the *flatness* property of the theory of contexts – cf. (Buvač et. al. 1995). In this case, the problem is structural and its resolution would require essentially a new logical theory of contexts.

4 Conclusions

Many of the research tasks that quite naturally occur in the Humanities – such as considering different points of view; selecting between competing interpretations or textual variants; capturing the shift of the research debate; and similar – can be effectively represented and reasoned about using microtheories.
We discussed source, belief, temporal and background microtheories. Source microtheories track the origins of information. The belief microtheories track the assumptions held by conceptual works or agents. Temporal microtheories structure the timelines – either Gregorian or "story-time" – for the information. Background microtheories finally capture the implicit assumptions that a set of microtheories share and grounds them in a common world view.
While the power of contexts places a significant burden on the ontological reasoning system and its maintainers – CYC only implements a subset of the capabilities that Lenat, Buvač and others have identified for contexts – we argue that contexts are indispensable for research in the Humanities.

5 Appendix: A Detailed Example

We will now provide a detailed example to show how some of these individual microtheories uses interact. The topic of our example is an analysis of the Christmas stories in the Gospels of Matthew and Luke.
Matthew and Luke want to show that Jesus of Nazareth is the Messiah; this calls for our modal statement and projection microtheory setup.

```
In Mt: GospelOfMatthewIntentionMt.
f: (beliefs (AuthorFn Matthew-BookOfBible)
     (isa JesusOfNazareth Messiah)).

In Mt: GospelOfMatthewMt.
f: (isa JesusOfNazareth Messiah).

In Mt: GospelOfLukeIntentionMt.
f: (beliefs (AuthorFn Luke-BookOfBible)
     (isa JesusOfNazareth Messiah)).

In Mt: GospelOfLukeMt.
f: (isa JesusOfNazareth Messiah).
```

From the Old Testament, specifically its prophecies, Matthew and Luke know that the Messiah has to be born in Bethlehem. From the historical life of Jesus of Nazareth, however, they also know that Jesus has to end up living his childhood in Nazareth — as his name suggests.

The Prophetic Precondition

The prophetic passage regarding the location of the birth is the prophet Micah 5:2:

> 'But you, Bethlehem, in the land of Judah
> are by no means least among the rulers of Judah;
> for out of you will come a ruler
> who will be the shepherd of my people Israel.'

The prophetic passage regarding the virgin birth is in Isaiah 7:14:

> The virgin will be with child and will give birth to a son,
> and they will call him Immanuel—which means, "God with us."

The critical aspects that the two gospels amalgamate from these two prophetic passages can be represented as follows:

```
In Mt: MessianicPropheciesMt.
f: (implies
      (and
        (isa ?SON MalePerson)
        (isa ?VIRGIN Virgin)
        (isa ?B-DAY BirthingEvent)
        (birthChild ?B-DAY ?SON)
        (birthParent ?B-DAY ?VIRGIN)
        (locationOf ?B-DAY Bethlehem))
      (isa ?SON Messiah)).
```

The Historical Precondition

The basic problem is expressed by the following rule:

```
In Mt: FertileCrescentNamingConventionMt.
f: (implies
      (and
         (isa ?PERSON FamousPerson)
         (isa ?EVENT Childhood)
         (animateActedOn ?EVENT ?PERSON)
         (locationOf ?EVENT ?TOWN)
         (firstName ?PERSON ?NAME))
      (ist EnglishLexiconMt
         (commonNickName ?PERSON
             (WordConcatenationFn ?NAME Of-TheWord ?TOWN))).
```

This means that the narrative of the childhood of Jesus has to end in the village of Nazareth in Galilee.

The Differences in the Christmas Narratives

Now we get into the individual differences between the two narratives as provided by Matthew and Luke. It will become immediately obvious that these two narratives could not co-exist in the same context of reasoning without inducing contradictions.

For the announcement of the birth, we consider the following differences:

1. Who is the recipient of the announcement?
2. Does the announcement precede the beginning of the pregnancy?
3. Where and when does the announcement occur?

```
Constant: AnnouncementOfBirthOfMessiah.
In Mt: SharedNewTestamentMt.
isa: AnnouncingSomething.
ibtGenerated: BirthOfMessiah-IBT.
```

Notice that the contents of the information bearing thing, the angelic message, would also be represented as a context of its own, a propositional information thing derived from the information bearing thing that is the announcement. While these announcements differ slightly, they are similar enough that for our current purposes we can use the following representational approach:

```
In Mt: BaseMt.
f: (genlMt (PITofIBTFn BirthOfMessiah-IBT) SharedNewTestamentMt).
In Mt: (PITofIBTFn BirthOfMessiah-IBT).
f: (thereExists ?EVENT
```

```
    (and
      (thereExists ?SON
        (isa ?EVENT Birth)
        (birthParent ?EVENT Mary-MotherOfJesus)
        (birthChild ?EVENT ?SON)
        (isa ?SON MalePerson)
        (nameString ?SON "Jesus"))
      (startsAfterEndOf ?EVENT AnnouncementOfBirthOfMessiah)).
```

Now we get to the key differences. First, the recipients are different:

```
In Mt: GospelAccordingToLukeMt.
senderOfInfo: Gabriel-ArchAngel.
f: (intendedAudience BirthOfMessiah-IBT Mary-MotherOfJesus).

In Mt: GospelAccordingToMatthewMt.
senderOfInfo: (SomeFn Angel).
f: (intendedAudience BirthOfMessiah-IBT Joseph-FatherOfJesus).
```

Secondly, the temporal relationship to the pregnancy differs:

```
In Mt: SharedNewTestamentMt.
Constant: MiraculousPregnancyOfMaryWithJesus.
isa: Pregnancy.
physiologicalConditionAffects: Mary-MotherOfJesus.

In Mt: GospelAccordingToLukeMt.
f: (startsAfterEndOf MiraculousPregnancyOfMaryWithJesus
AnnouncementOfBirthOfMessiah).

In Mt: GospelAccordingToMatthewMt.
f: (startsAfterStartOf AnnouncementOfBirthOfMessiah
MiraculousPregnancyOfMaryWithJesus).
```

For right now we will gloss over the fact that one of the announcements happened inside a dream (as they always do in the Gospel of Matthew), while the other happens in broad daylight in Mary's house (which presumably means in the house of her parents). But we can capture the fact that the announcements happened in the different cities:

```
In Mt: GospelAccordingToLukeMt.
f: (eventOccursAt AnnouncementOfBirthOfMessiah NazarethGalilee).

In Mt: GospelAccordingToMatthewMt.
f: (eventOccursAt AnnouncementOfBirthOfMessiah BethlehemJudea).
```

With respect to establishing the location of the birth of Jesus, we will look at two questions:

1. What do Mary and Joseph have to do to be in Bethlehem?
2. Where does the birth take place?

We have already pointed out that according to Matthew, Joseph and Mary lived in Bethlehem all along, which in Luke they have to travel to Bethlehem, based on a census ordered by Roman emperor August.

```
In Mt: GospelOfMatthewMt.
f: (residesInRegion Mary-MotherOfJesus BethlehemJudea).
f: (residesInRegion Joseph-FatherOfJesus BethlehemJudea).
```

```
In Mt: GospelOfLukeMt.
f: (residesInRegion Mary-MotherOfJesus NazarethGalilee).
f: (residesInRegion Joseph-FatherOfJesus NazarethGalilee).

Constant: JourneyToBethlehemForCensus.
isa: Travel-TripEvent.
doneBy: Joseph-FatherOfJesus, Mary-MotherOfJesus.
fromLocation: NazarethGalilee.
toLocation: BethlehemJudea.
```

Now that we have the holy couple securely in Bethlehem ready to fulfill the prophecy, we can describe the birthing event.

```
In Mt: BirthOfTheMessiah.
isa: BirthEvent.
birthParent: Mary-MotherOfJesus.
birthChild: JesusOfNazareth.

In Mt: GospelOfMatthewMt.
Constant: HouseOfJosephInBethlehem.
isa: House.
f: (owns Joseph-FatherOfJesus HouseOfJosephInBethlehem).
f: (eventOccursAt BirthOfTheMessiah HouseOfJosephInBethlehem).

In Mt: GospelOfLukeMt.
Constant: StableWhereJesusWasBorn.
isa: Stable.
internalSubRegion: BethlehemJudea.
adjacentTo: (SomeFn HotelBuilding).
f: (eventOccursAt BirthOfTheMessiah StableWhereJesusWasBorn).
```

There is at least one subtle mistake in the representation given so far; specifically, we glossed over the fact that the temporal extent of the microtheory contexts is in some cases larger than is appropriate for the facts stated. The individual events are fine — here the actor and role assignments are understood to be restricted to the temporal extent of event, not to the temporal extent of the enveloping context. But the residency statements about Mary and Joseph are problematic:

```
In Mt: GospelOfMatthewMt. ;; WRONG WRONG WRONG WRONG
f: (residesInRegion Mary-MotherOfJesus BethlehemJudea).
f: (residesInRegion Joseph-FatherOfJesus BethlehemJudea).
```

As written, this is false, because they also reside in Egypt for a couple of years and then they move to Nazareth altogether as discussed before. Anything asserted in the `GospelOfMatthewMt` would have temporal extent to the whole of the story time as narrated, i.e. from the time of the opening genealogy to Jesus' ascension at the end of the Gospel.

In general, temporal qualification is usually understood to mean mapping statements to an absolute timeline, like the Julian calendar.

```
In Mt: GospelOfMatthewMt.
Time Dimension: (TimeIntervalInclusiveFn
  (YearBCE-JulianFn 7) (YearBCE-JulianFn 3)).
Time Parameter: Time-Point.
f: (residesInRegion JesusOfNazareth BethlehemJudea).
```

However, for our situation this is often inappropriate; for many of the events recounted here, neither dates nor rough estimates are available. Fortunately, temporal qualification is not restricted to absolute dates. Rather, the temporal constraints of an event can be pushed up into the temporal dimension of the context specification. This allows modeling the constraints in terms of story time, as long as the events themselves are temporally related to each other in terms of their sequence.

```
In Mt: GospelOfMatthewMt.
Constant: HolyFamilyHidingInEgypt.
isa: Event.
startsAfterEndOf: BirthOfTheMessiah.
endsBeforeStartOf: HolyFamilyBackInNazareth.
f: (subEvents
  ChildhoodOfJesusOfNazareth HolyFamilyHidingInEgypt).

Time Dimension: (TemporalExtentInMtFn
  HolyFamilyHidingInEgypt GospelOfMatthewMt)
Time Parameter: Time-Point.
f: (residesInRegion JesusOfNazareth Egypt).
```

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