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Coherence Across Components in Cognitive Systems – One Ontology to Rule Them All

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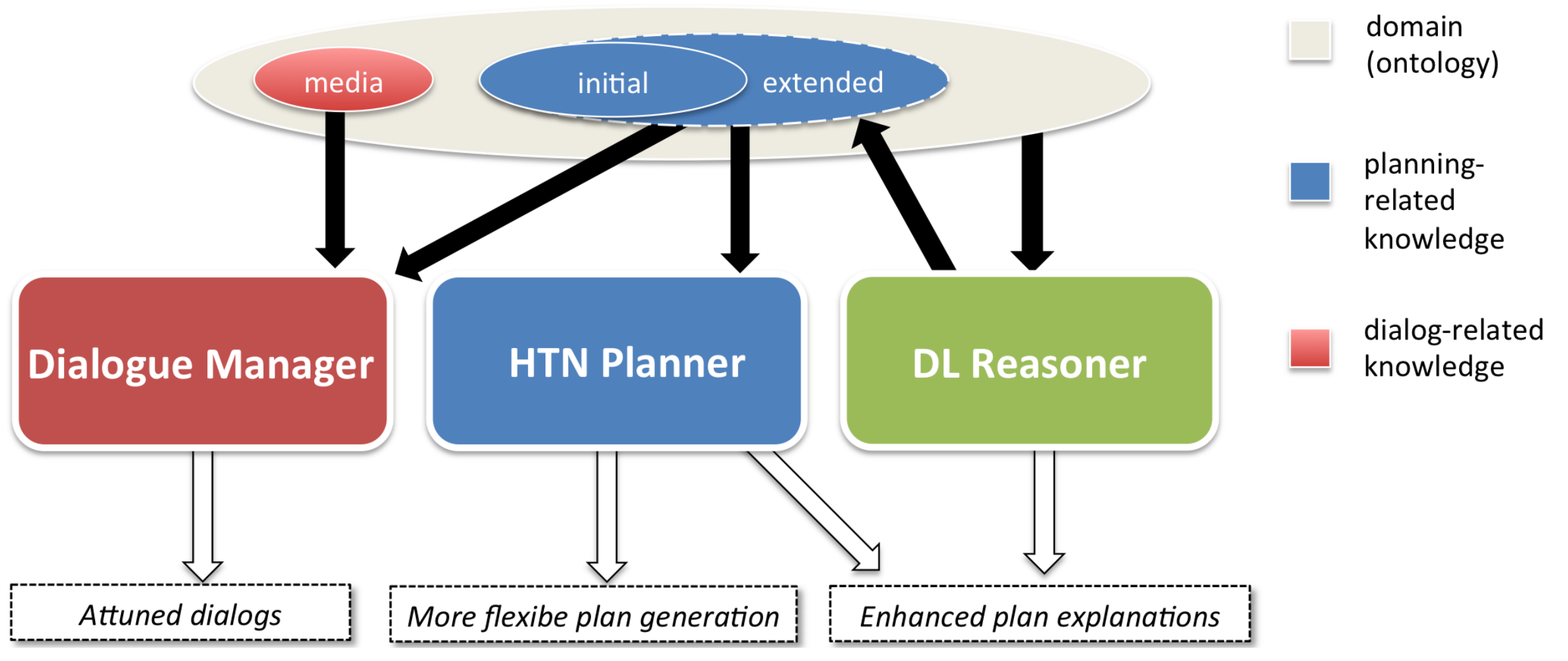
Approach

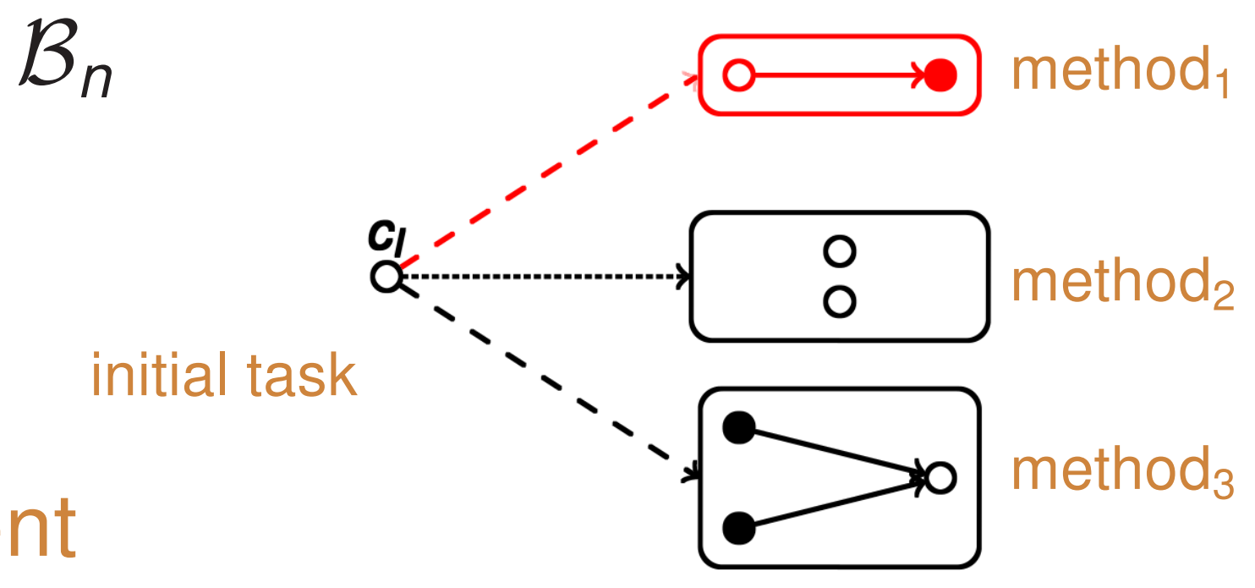
- Addressed problem: Specialised components in cognitive systems (e.g. planning, reasoning, UI) traditionally use separate knowledge representation formalisms (redundancy, complicates maintenance)
- This approach: knowledge models for specialised components of a cognitive system are generated from a single resource (ontology)



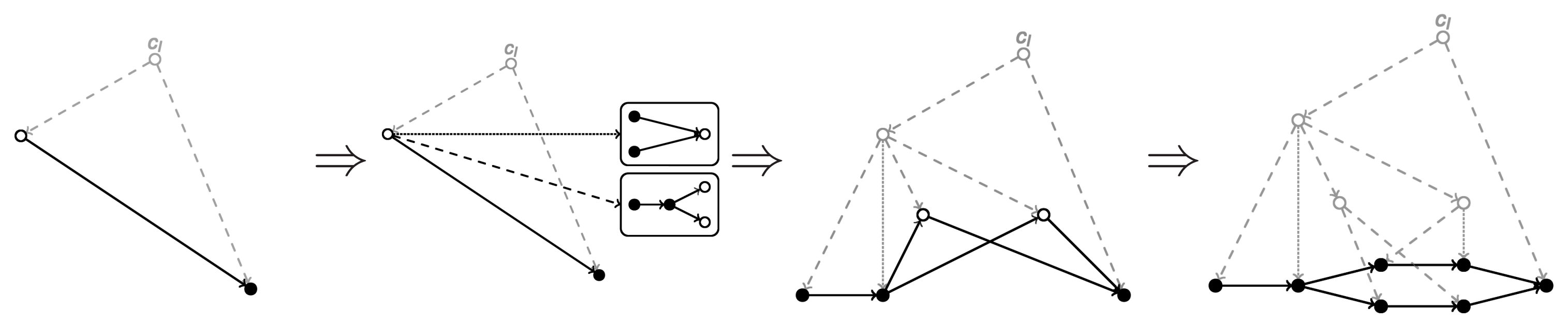
- Integration of planning domain into ontology such that it
  - (i) can be used by standard HTN planners
  - (ii) can be automatically extended using standard DL reasoners
  - (iii) links to and uses general knowledge in the domain
- Plan explanations incorporate background domain knowledge (extending "traditional" plan explanation)
- Application scenario: Fitness domain – system generates training plan (schedule, exercises, rest days) for a user pursuing a fitness objective
- Integrating the user: Use of a shared knowledge source (ontology) considerably facilitates coherency of the interaction
  - (i) it can be used to create dialog hierarchy and structure that are attuned to the planning domain
  - (ii) it enables smooth integration of predefined declarative explanations [2] with dynamically generated plan and ontology explantions
  - (iii) it enables the individualization of the ongoing dialog according to the user's needs, requirements, or preferences (e.g. present only exercises with dumbbells)

Hierarchical Task Network (HTN) Planning

- Primite (directly executable) and abstract tasks
- Abstract tasks are decomposed into subtasks by methods, denoted $\mathcal{A} \mapsto_{\prec} \mathcal{B}_1, \ldots, \mathcal{B}_n$
- Example



Plan refinement



Embedding Planning Methods in Ontologies

Planning Domain	DL Representation
$\mathcal{A} \mapsto \mathcal{B}$	
$\mathcal{B} = \mathcal{B}_1$	$B \sqsubseteq A$
$\mathcal{B} = \mathcal{B}_1, \mathcal{B}_2, \ldots, \mathcal{B}_n$	$\Theta\, includes.[B_1, \ldots, B_n] \equiv A$

with $\Theta r.(\{C_i\}_{i \in I}) := \sqcap_{i \in I} \exists r.C_i \sqcap \forall r.\left(\bigsqcup_{i \in I} C_i\right)$ (cf. [1])

- Planning tasks are represented as concepts ("task concepts")
- Correspondence theorem: subsumption of task concepts defined using Θ corresponds to valid decomposition in the planning domain

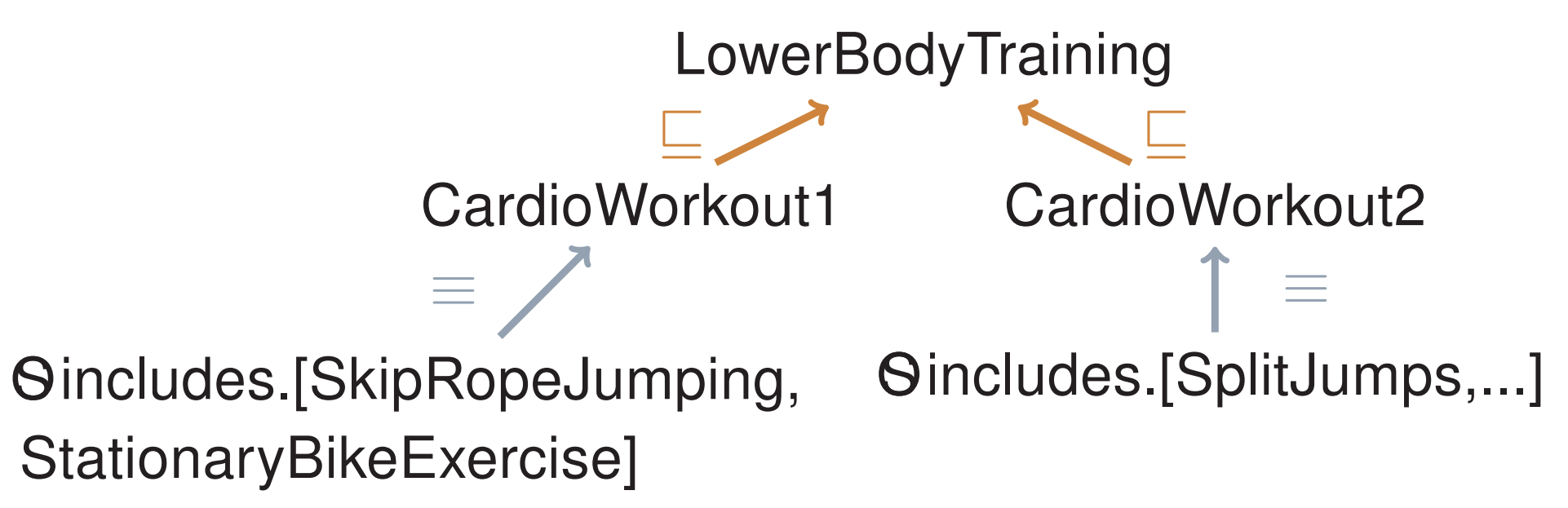
Extending Planning Domains by DL Inference

- Infer HTN decompositions by DL classification in the domain ontology

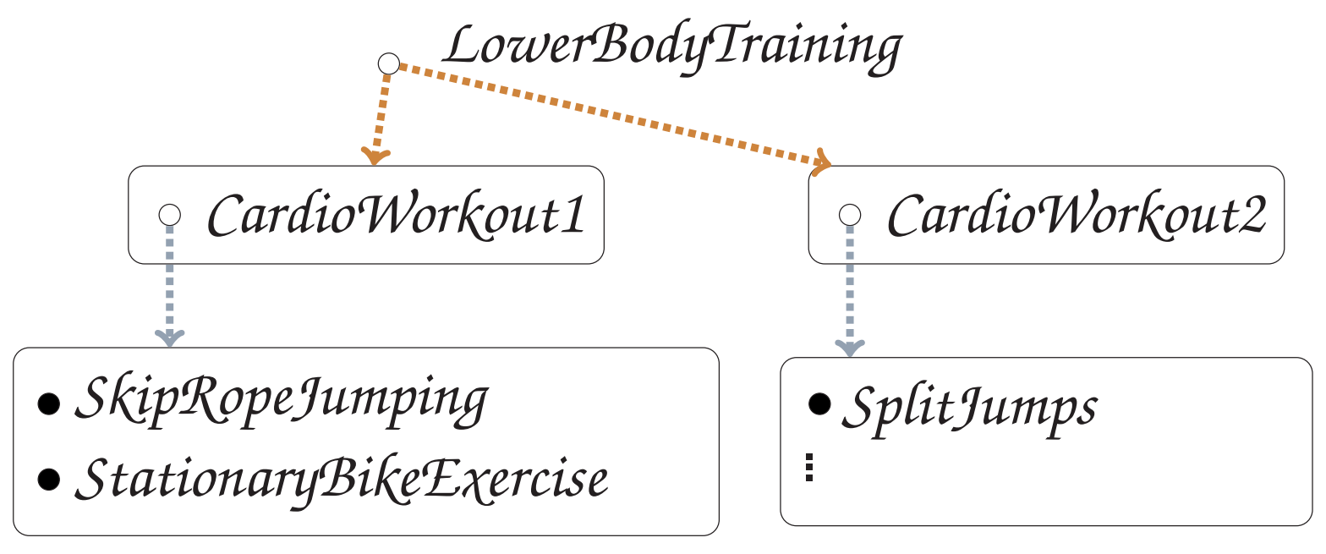
Initial definitions

$$\begin{aligned} LowerBodyTraining &\equiv \Theta includes.[\exists trains.\exists partOf.LowerBody] \\ CardioWorkout1 &\equiv \Theta includes.[SkipRopeJumping, StationaryBikeExercise] \\ CardioWorkout2 &\equiv \Theta includes.[SplitJumps, \ldots] \\ SkipRopeJumping &\sqsubseteq \exists trains.GastrocnemiusMuscle \sqcap \\ &\quad \exists engages.QuadricepsFemorisMuscle \sqcap \\ &\quad \exists engages.Hamstring \end{aligned}$$

Inferred subsumptions



Generated HTN methods



- Combinations of task concepts are generated and classified; corresponding decomposition methods are introduced

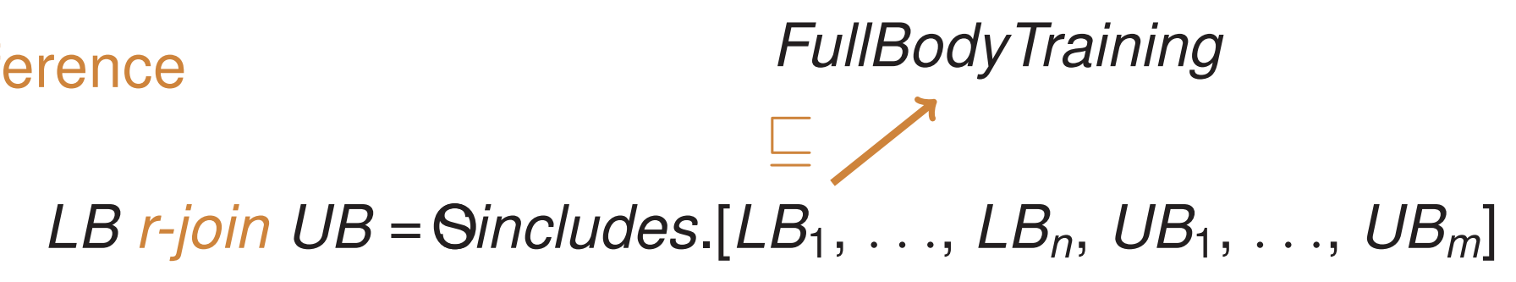
Provided

$$\begin{aligned} FullBodyTraining \equiv \Theta includes.[&\exists engages.(\exists partOf.LowerBody), \\ &\exists engages.(\exists partOf.UpperBody)] \end{aligned}$$

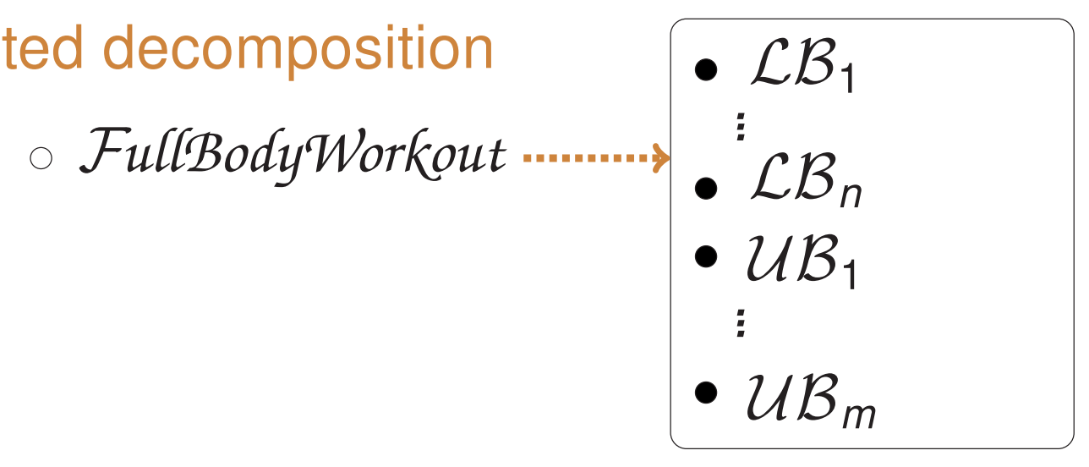
$LB \equiv \Theta includes.[LB_1, \ldots, LB_n]$ ...lower body exercises

$UB \equiv \Theta includes.[UB_1, \ldots, UB_m]$ ...upper body exercises

Inference



Generated decomposition

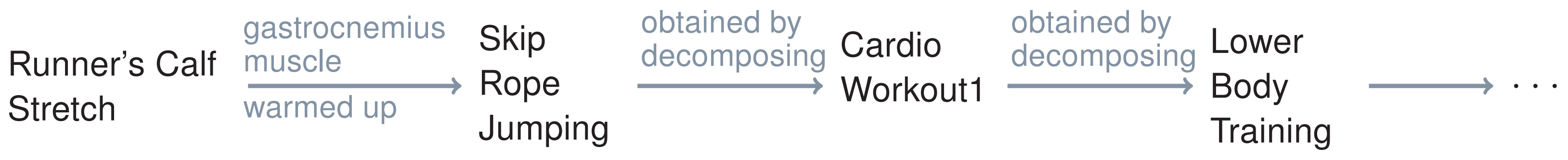


Application in the Fitness Domain

- Initial planning domain: 310 tasks, a few methods, 9 training objectives and 24 workout templates
- Extended planning domain: 471 tasks and 967 methods (the computation takes 3.6 seconds using Intel® Core™ i5-4300U and off-the-shelf reasoner FaCT++ [5])

Explanations

- Example: User receives a plan including the *runner's calf stretch*, inquires *why*?



- Plan explanation (traditional, cf. [4]):

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The runners' calf stretch is necessary as it ensures that the gastrocnemius muscle
is warmed up, which is needed by the skip rope jumping.  The skip rope jumping is
necessary, since it is part of the cardio workout no.1.  The cardio workout no.1
is necessary, since it is part of the lower body training.  ...
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- Again; why? (use ontology-based extended explanation mechanism [3]):

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According to its definition, cardio workout no.1 includes skip rope jumping and
stationary bike exercise.  Skip rope jumping engages the gastrocnemius muscle which
is something that is part of the lower body.  ...  [etc.]
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Conclusion

- A coherent knowledge model for both planning and reasoning, enabling coherent and detailed explanations for the user
- We established the semantic correspondence between HTN planning methods and their representation in the ontology
- A system prototype is used in the *Collaborative Research Centre SFB/TRR 62* "A Companion-Technology for Cognitive Technical Systems" funded by DFG (German Research Foundation)
- Future work: incorporate mixed-initiative planning, adapt verbosity of explanations wrt. pragmatics and user modelling, enable DL reasoning about the order of tasks

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