Representation and Learning of Hierarchical Knowledge Structures

Nick Harley

njharley@ai.vub.ac.be

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ARTIFICIAL
INTELLIGENCE
RESEARCH GROUP

1. Introduction
2. CHAKRA
3. IDyOMS
4. Applications
5. Future Work

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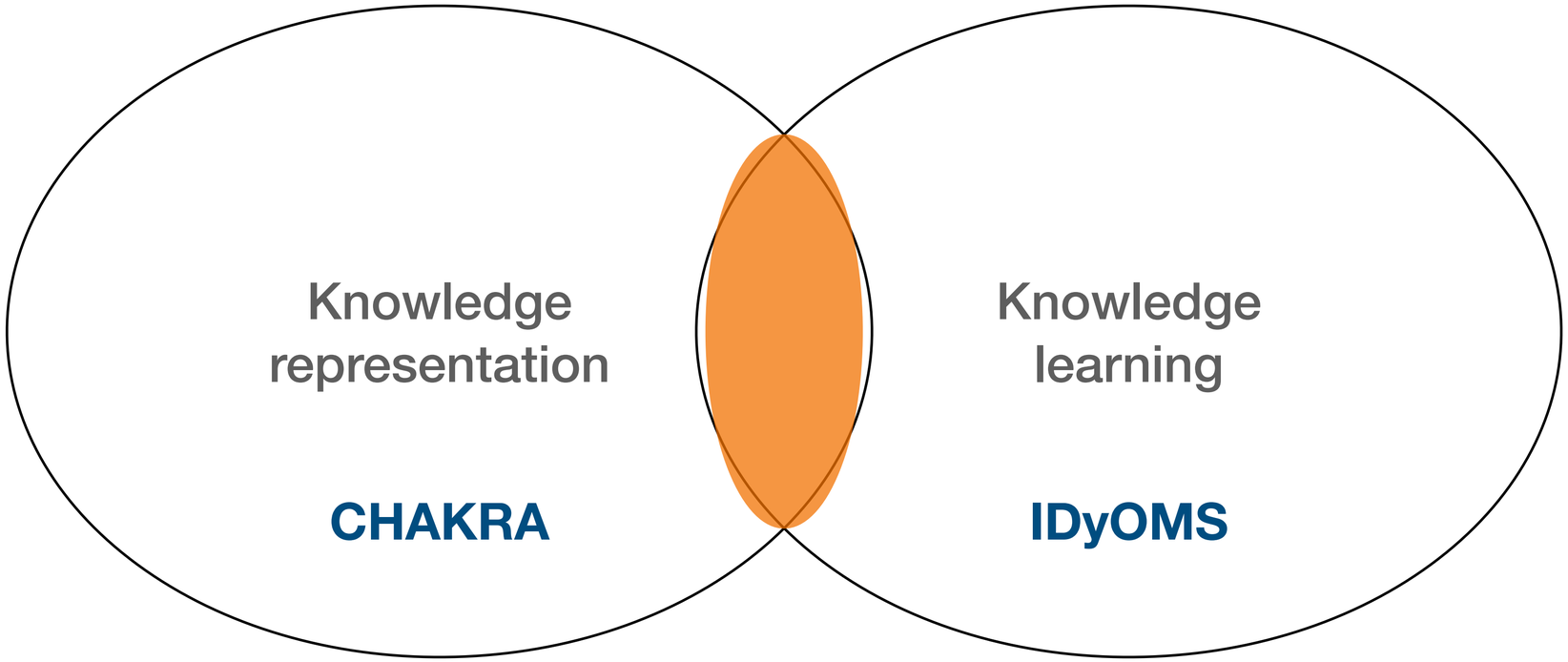

- Hierarchical knowledge structures
- Ontology, logic and reasoning
- Programming languages and type theory

- Statistical predictive models
- Information theoretic models
- Unsupervised learning of knowledge structures

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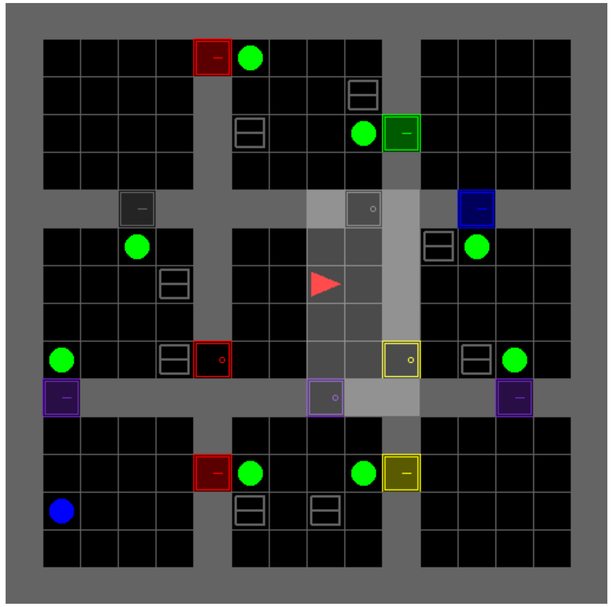
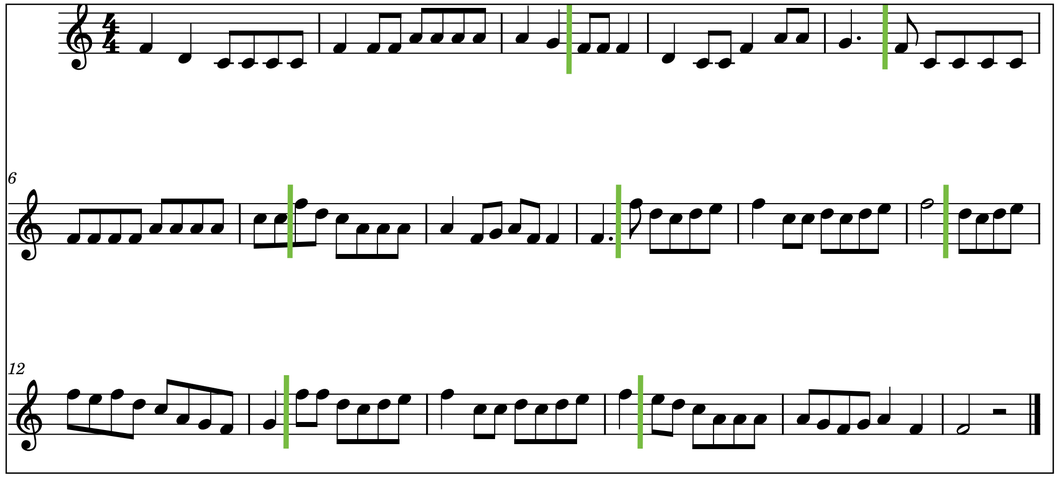
AI Assisted Operator

Gridworld agent behaviour





Cognition of musical melodies

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Common Hierarchical Abstract Knowledge Representation for Anything

CHAKRA is a general purpose knowledge representation system for integrating and reasoning over heterogeneous data.

- Based on CHARM (Wiggins, 1989) and Harley, 2019

Common Hierarchical Abstract Knowledge Representation for Anything

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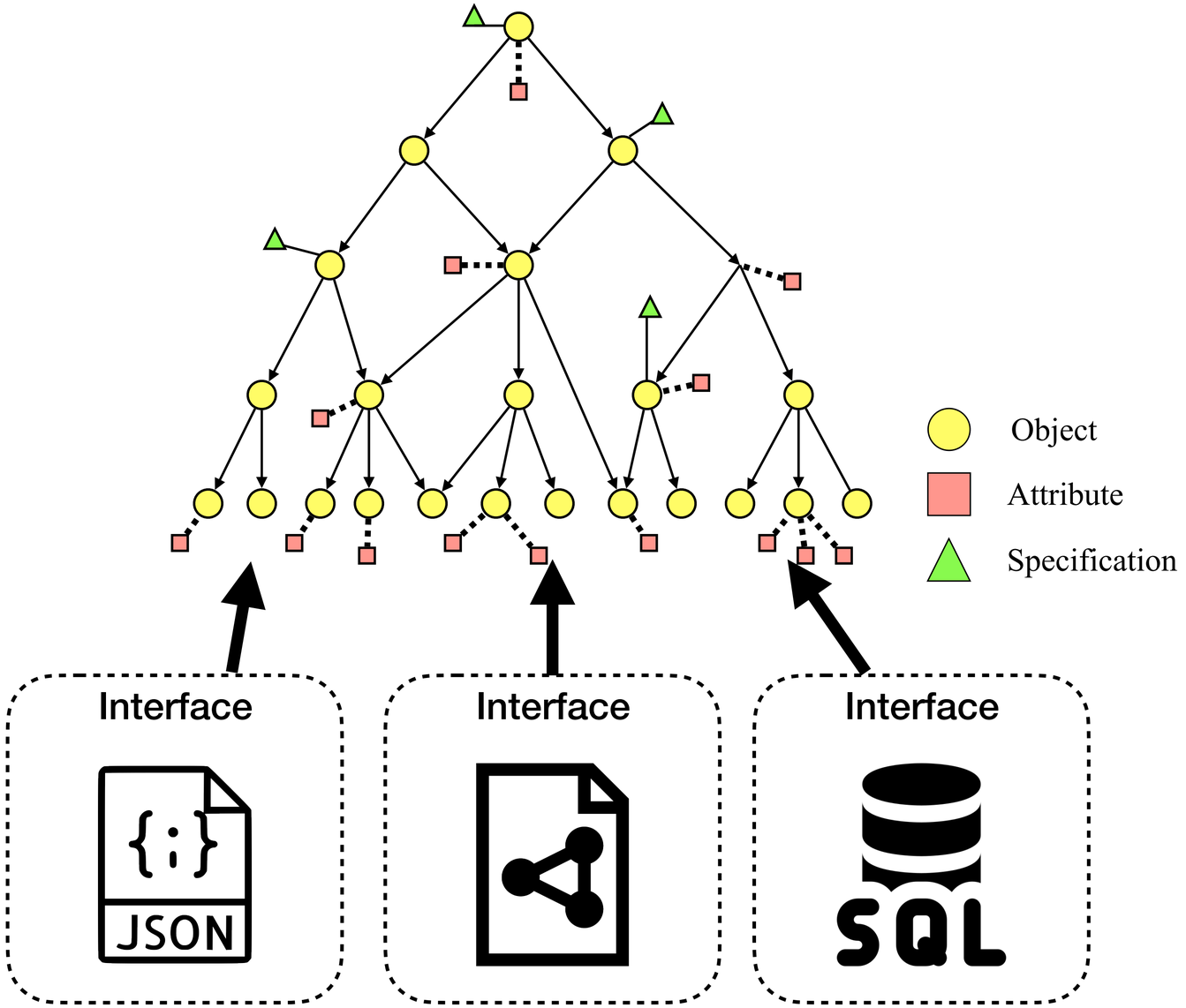

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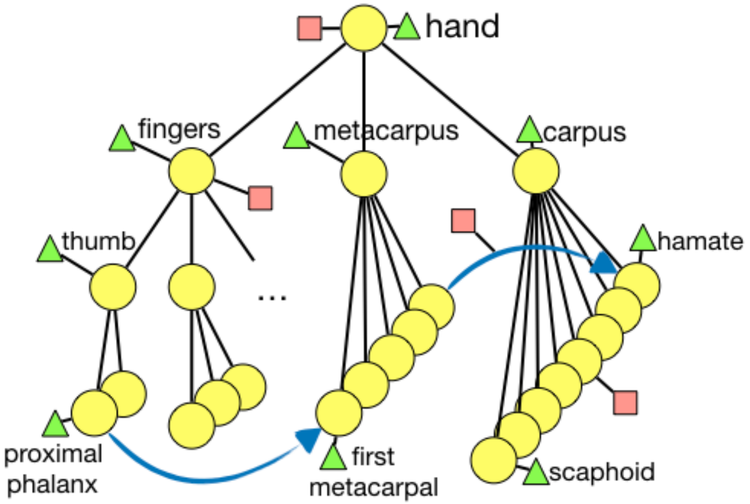

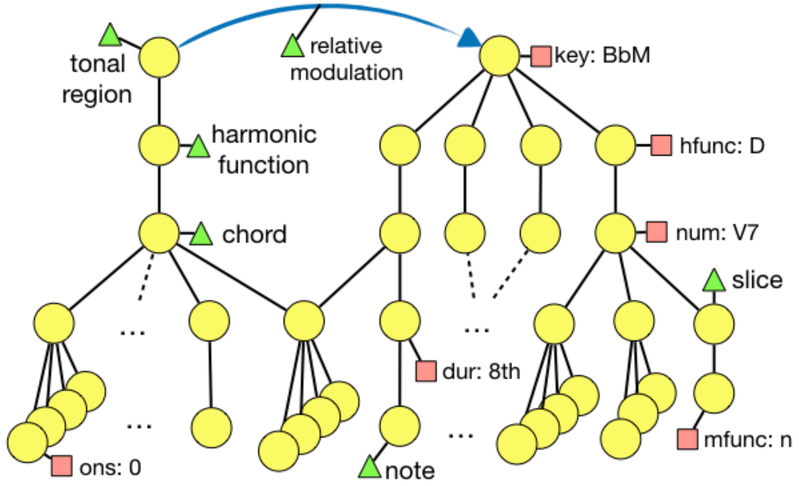

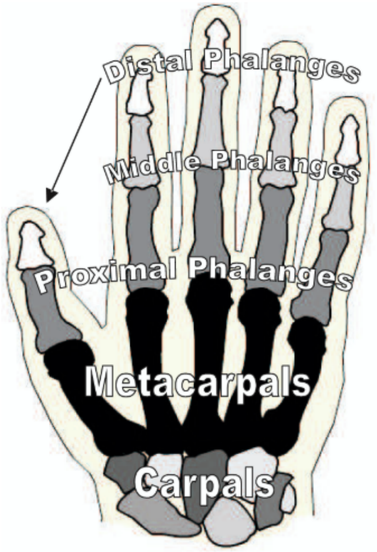

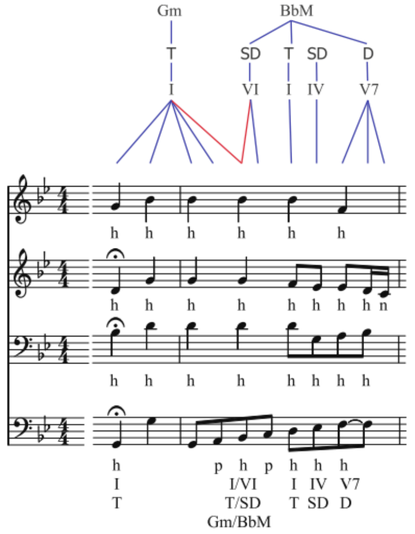

Common Hierarchical Abstract Knowledge Representation for Anything

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Specification in Coq:

https://nick-harley.github.io/chakra-coq/chakra.html

Implementation in Julia:

https://github.com/nick-harley/Chakra

julia

The Information Dynamics of Multidimensional Sequences

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IDyOMS is a predictive model for finding statistical patterns in multidimensional sequence data.

- IDyOMS is a generalisation of IDyOM (Pearce, 2005).
- It is a multiple viewpoint system (Conklin & Witten, 1995).
- It uses PPM (Cleary & Witten, 1984).
- It uses entropy (Shannon, 1948).

The Information Dynamics of Multidimensional Sequences

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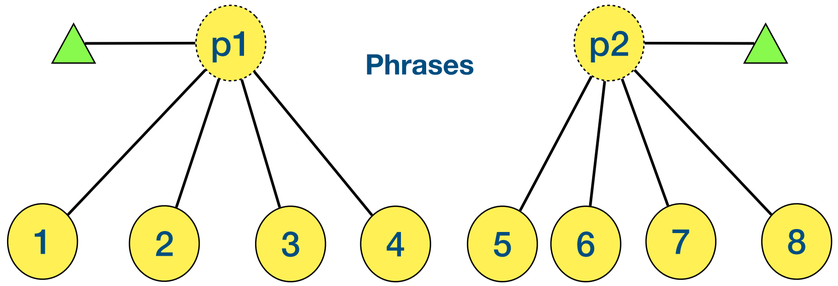

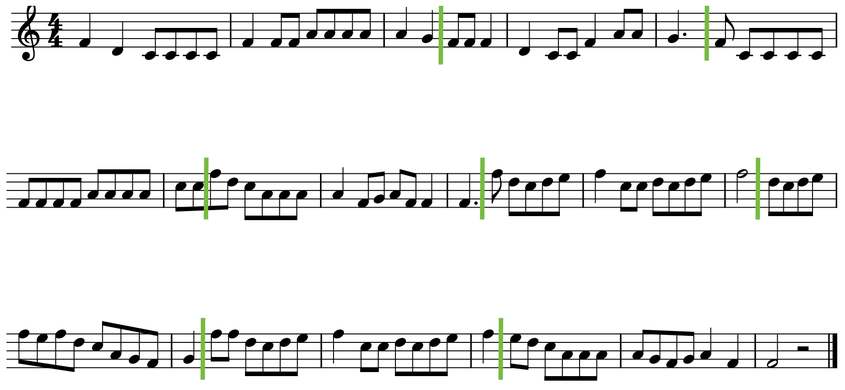

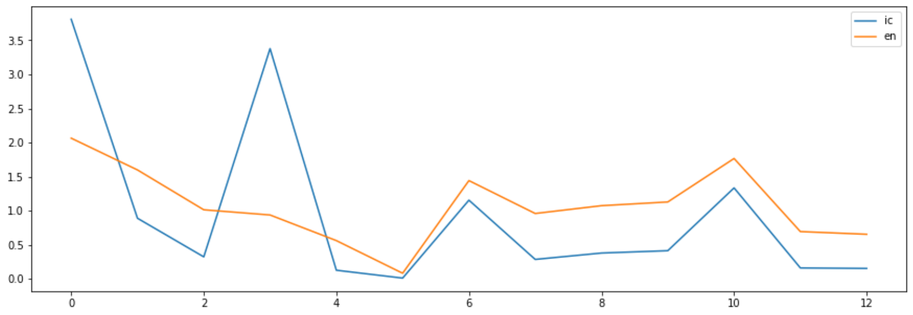

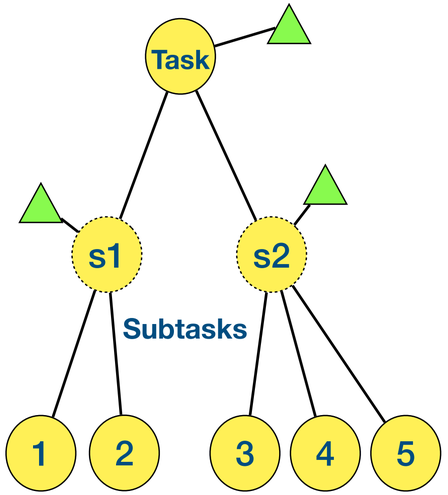

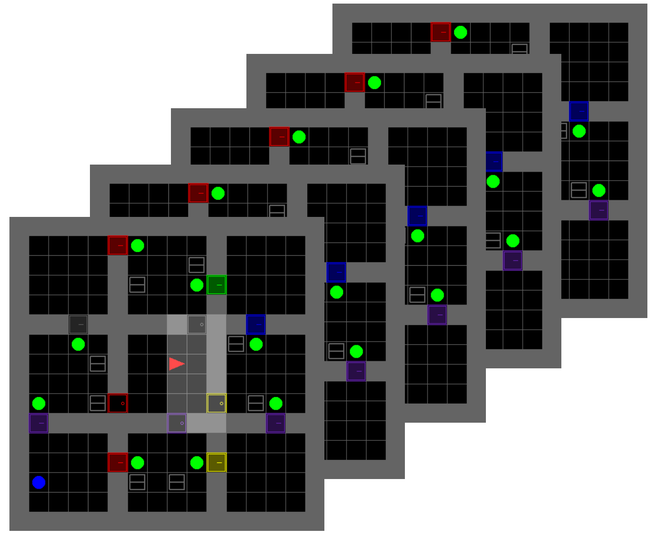

The Information Dynamics of Multidimensional Sequences

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Implementation in Julia:

https://github.com/nick-harley/Idyoms

AI Assisted Operator

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Goal: Integration and reasoning over heterogeneous data sources using CHAKRA.

AI Assisted Operator

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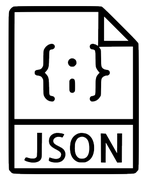
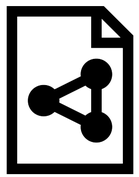
- Historical execution data (SQL)
- Robot world model (RDF)
- Execution plans (PDDL)
- Assembly instructions (JSON)





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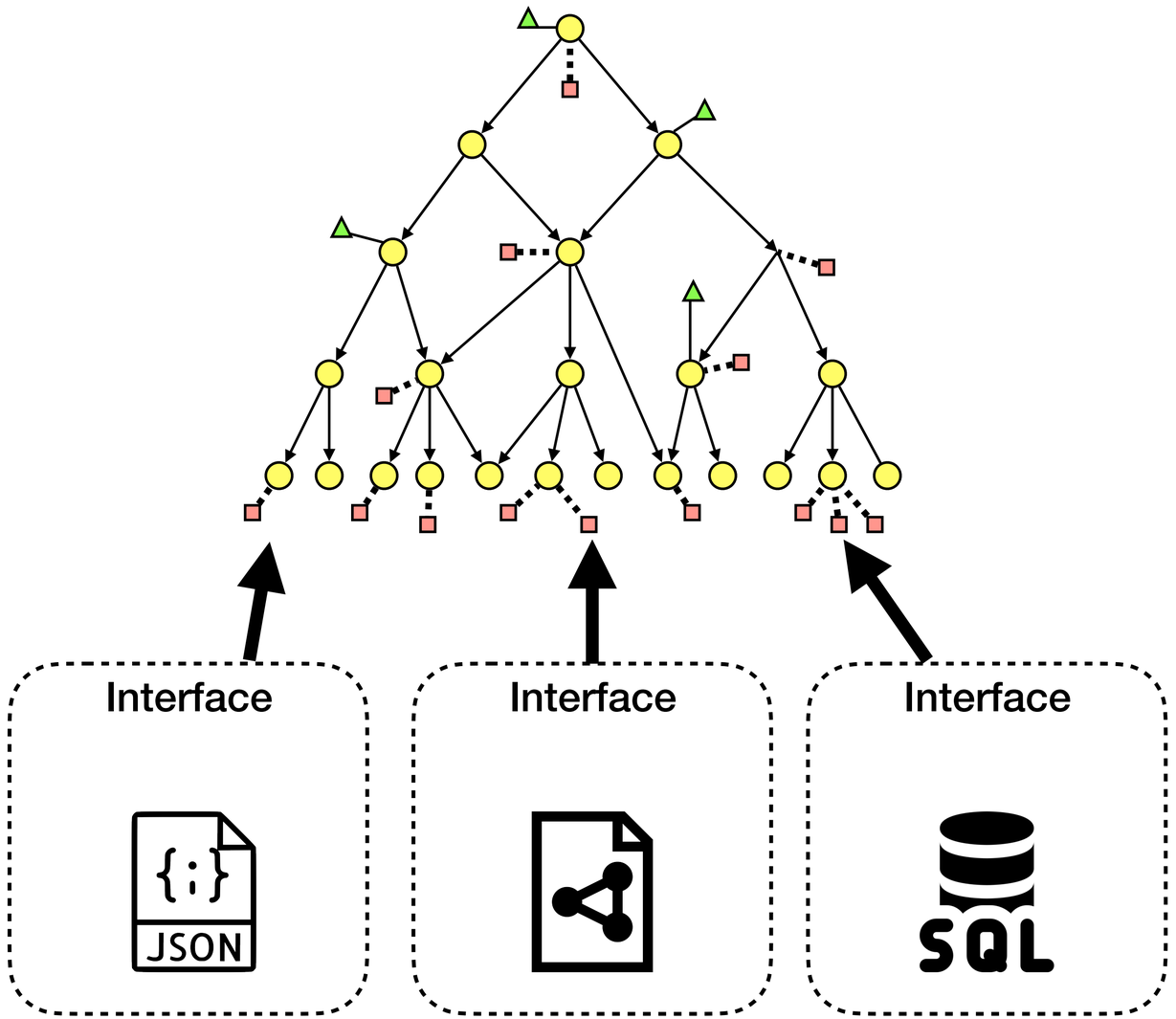

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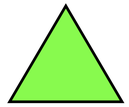
Example specification: an execution x of an assembly step y in which an operator error z occurred.



```
Exists x,y,R.
    IsExecutionOf(x,y,R) /\
    Exists z.
      HasPart(x,z) /\
      LogType(z,Error)
```

Gridworld Agent Behaviour

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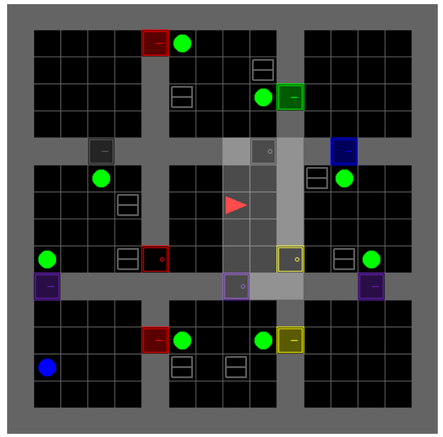
Goal: Unsupervised learning of subtask task knowledge from human demonstration sequences using IDyOMS.



Gridworld Agent Behaviour

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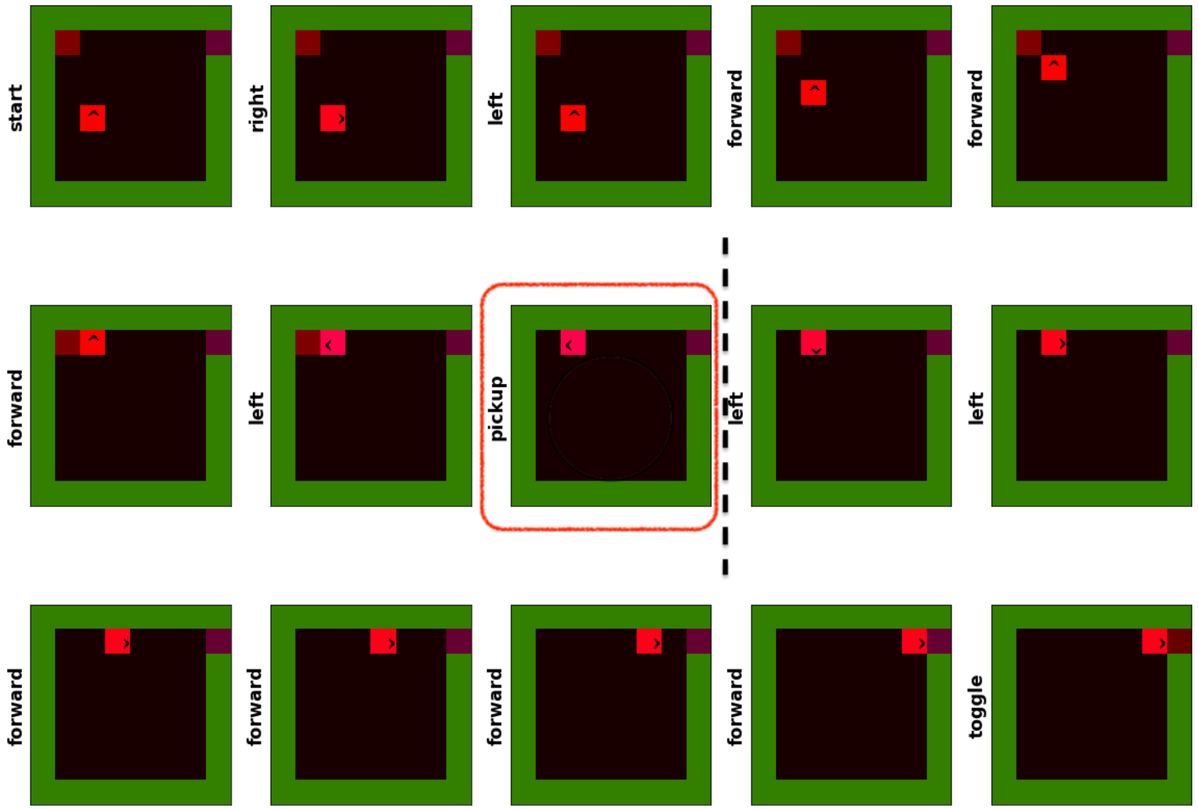

Task:

‘Open door’

Subtasks:

‘Pick up key’

‘Unlock door’

Gridworld Agent Behaviour

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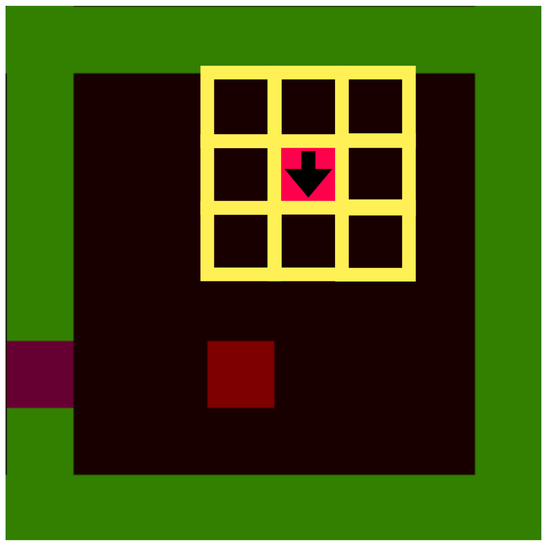
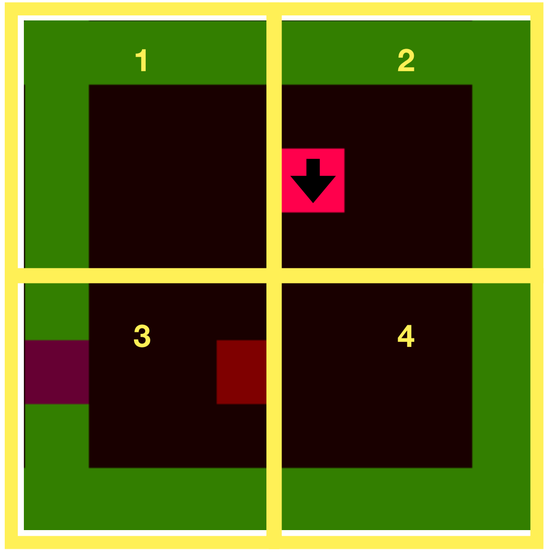
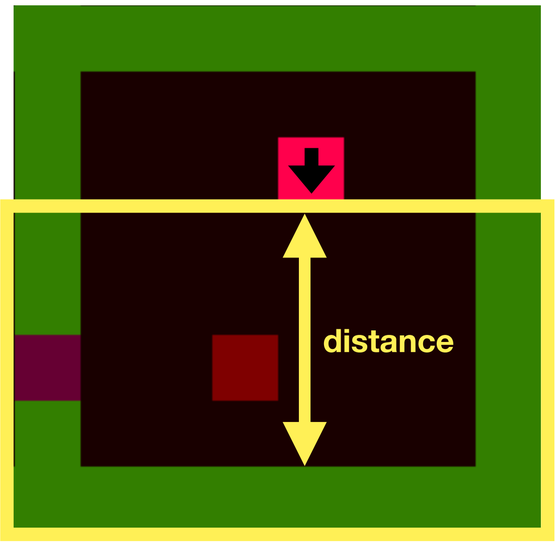
Human demonstration sequences are turned into multidimensional feature vectors.







Gridworld Agent Behaviour

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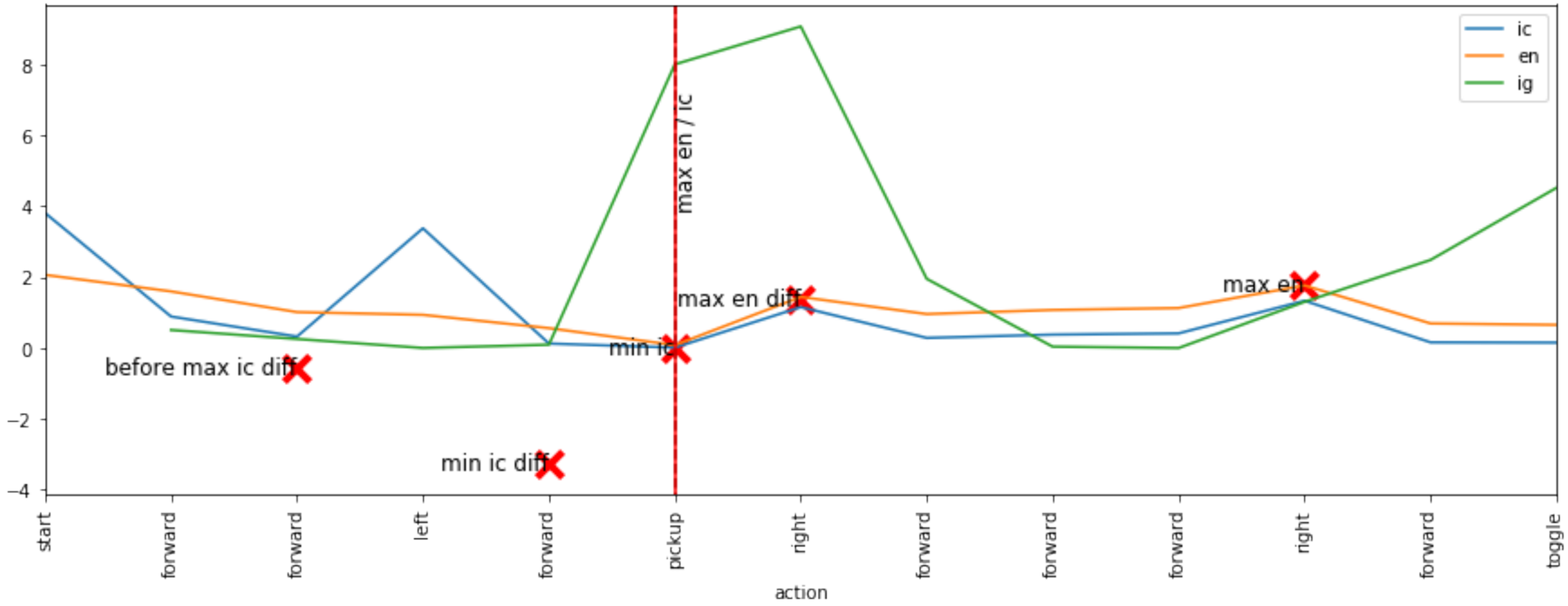
97% of subtask boundaries correctly identified.



https://nick-harley.github.io/idyog/

Music Cognition

1. Introduction
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Goal: Unsupervised learning of perceptual and cognitive representations of musical structures from sequence data using IDyOMS.

- Music is important and challenging from the perspective of computational creativity.
- Predictive models of music sequences might provide insight into general perception and cognition.

Music Cognition

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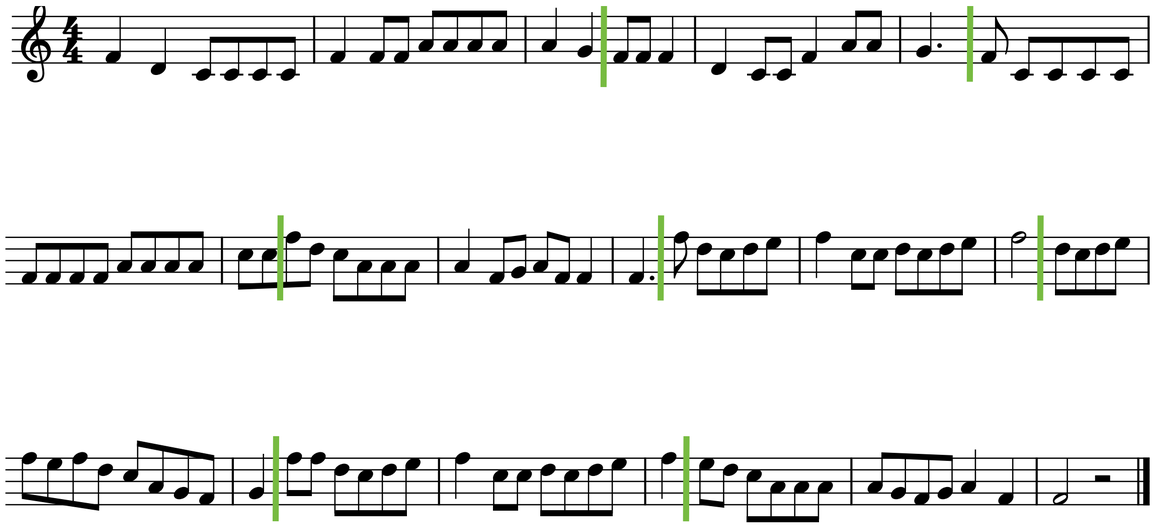
Melch is a large corpus of melodies with phrase boundary annotation represented in CHAKRA.



https://github.com/nick-harley/Melch

Music Cognition

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Viewpoints are used to construct a rich representation of musical structure.

	ONSET	DELTAST	BIOI	DUR	CPITCH	MPITCH	ACCIDENTAL	KEYSIG	MODE	BARLENGTH
	Int64	Int64	Int64	Int64	Int64	Int64	Int64	Int64	Int64	Int64
	0	0	1	24	65	38	0	-1	0	48
	24	0	24	24	62	36	0	-1	0	48
	48	0	24	12	60	35	0	-1	0	48
	60	0	12	12	60	35	0	-1	0	48
	72	0	12	12	60	35	0	-1	0	48
	84	0	12	12	60	35	0	-1	0	48
	96	0	12	24	65	38	0	-1	0	48
	120	0	24	12	65	38	0	-1	0	48

https://github.com/nick-harley/Melch

Music Cognition

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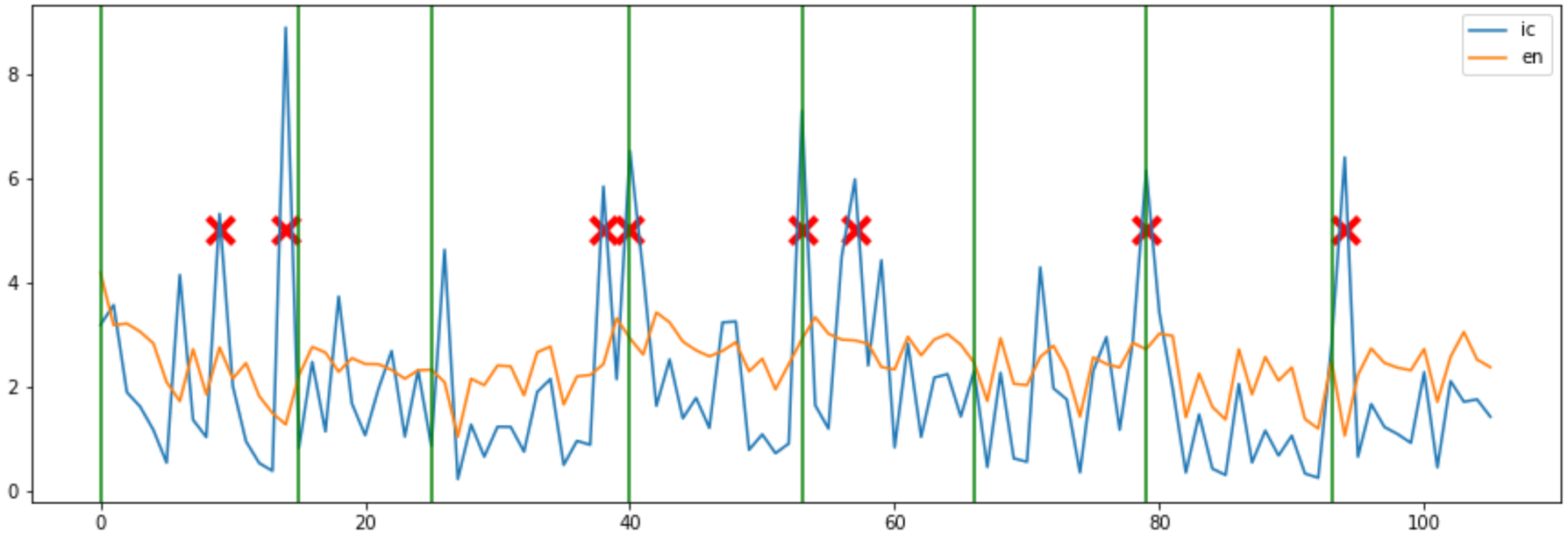
Musical phrase boundaries correspond very closely with prominent features in the information profiles of melodies.



AI Assisted Operator: Next Steps

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- Formalise ontologies for the various data source
- Implement CHAKRA interfaces for the data sources
- Perform simple queries on CHAKRA structures.

Gridworld: Next Steps

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- Study more complex tasks.
- Defined more general viewpoint representation.
- Perform automatic segmentation.
- Classification of segments.

Music Cognition: Next Steps

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- Recreate and improve upon previous results (Pearce & Wiggins 2006)
- Fine-grained segmentation of melodies.
- Automatic classification of segments.
- Higher-level predictive models of segment classes.

Long Term Objectives

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- Develop composable and reusable tools and resources.
- Integrate knowledge representations, learning and reasoning.
- Perform higher-level prediction and abstraction.

Open Challenges

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- What is the best way to generalise viewpoint representations?
- When should two segments / subsequences be considered equal?

References

- Wiggins, G. A., Harris, M., & Smaill, A. (1989). Representing Music for Analysis and Composition. In M. Balaban, K. Ebcioglu, O. Laske, C. Lischka, & L. Soriso (Eds.), Proceedings of the Second Workshop on AI and Music (Issue 504, p. 10). AAAI.
- Harley, N. J., (2019). Abstract Representation of Music: A type-based knowledge representation framework. PhD dissertation.
- Pearce, M. T. (2005). The construction and evaluation of statistical models of melodic structure in music perception and composition.
- Cleary, J. & Witten, I. (1984). Data Compression Using Adaptive Coding and Partial String Matching. In IEEE Transactions on Communications, vol. 32, no. 4, pp. 396-402, April.
- Shannon,C.E.(1948).A mathematical theory of communication. Bell System Technical Journal, 27(3), 379–423 and 623–656.
- Conklin, D., & Witten, I. H. (1995). Multiple viewpoint systems for music prediction. Journal of New Music Research, 24(1), 51–73.
- Pearce, M.T., Müllensiefen, D., & Wiggins, G. A. (2010). The role of expectation and probabilistic learning in auditory boundary perception: A model comparison. Perception, 39(10), 1367–1391.
- Pearce, M. T., & Wiggins, G. A. (2006). EXPECTATION IN MELODY: THE INFLUENCE OF CONTEXT AND LEARNING. Music Perception, 23(5), 377–405.