

# Web Scale Music Analysis

A grand challenge in  
computational musicology

David De Roure



digital.humanities  
@ oxford



Semantic Media Network  
a new paradigm for navigable content for the 21st Century

# Overview

This talk is both *computational* and *social*

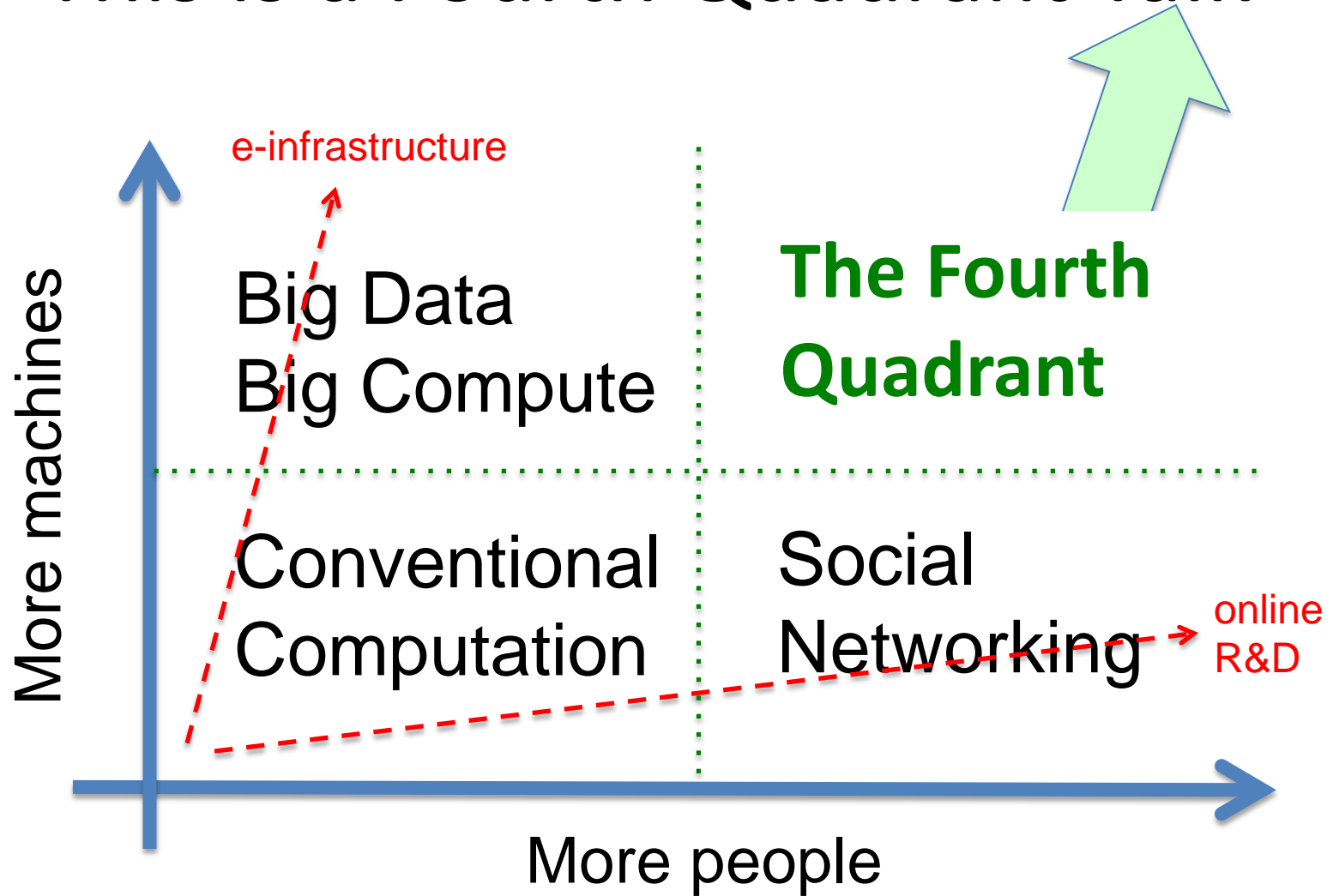
1. How is research done today?

- *Structural Analysis of Large Amounts of Music Information (SALAMI)* – a case study in Computational Musicology

2. What are the implications for our ‘knowledge infrastructure’?

- *Research Objects and Social Machines*

# This is a Fourth Quadrant Talk



# Here is the evidence, now what is the hypothesis? The complementary roles of inductive and hypothesis-driven science in the post-genomic era

Douglas B. Kell<sup>1\*</sup> and Stephen G. Oliver<sup>2</sup>

## Summary

It is considered in some quarters that hypothesis-driven methods are the only valuable, reliable means of scientific advance. Data-driven advances in scientific knowledge are marginal, irrelevant, insecure or wrong the development of technology—which might be of value—(beyond the recognition 'hypothesis-led'—must be seen as equivalent to the hypothetico-deductive scientific approach here that data- and technology-driven provide not alternatives to hypothesis-led knowledge discovery but are complementary partners with them. Many fields are hypothesis-poor. Here, computational analysis, which may be automated, provides generating novel hypotheses, especially in the genomic era. *BioEssays* 26:99-105, 2004 © 2003 Wiley Periodicals, Inc.



WIRED MAGAZINE: 16.07

SCIENCE : DISCOVERIES

## The End of Theory: The Data Deluge Makes Scientific Method Obsolete

By Chris Anderson 06.23.08



Illustration: Marian Bantjes



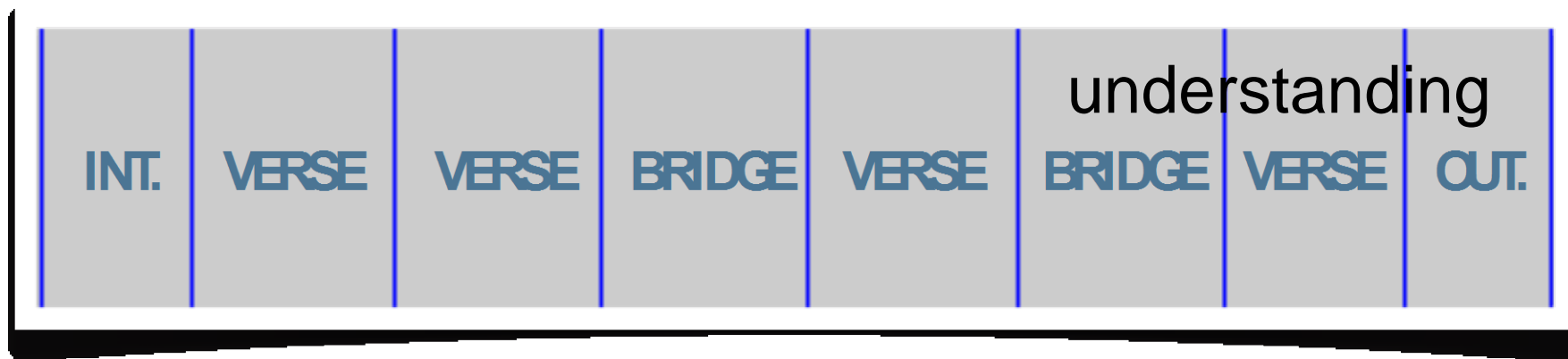
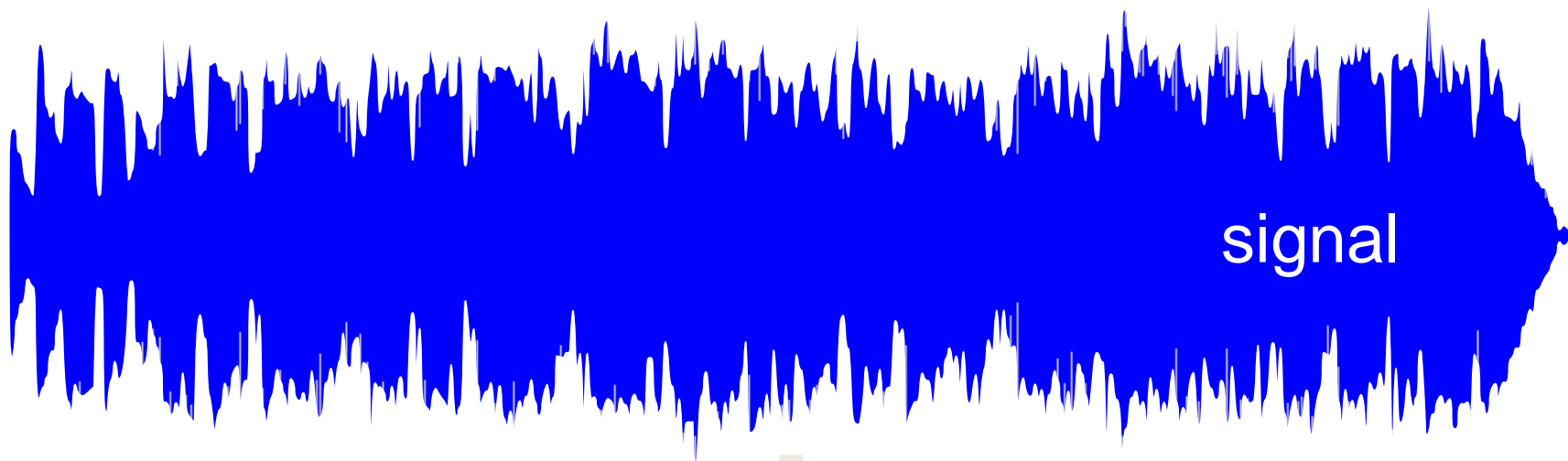
# FIRST PARADIGM

DATA-INTENSIVE SCIENTIFIC DISCOVERY

EDITED BY TONY HEY, STEWART TANSLEY, AND KRISTIN TOLLE



# The Problem



23,000 hours of recorded music



Digital Music Collections

Music Information Retrieval Community



Student-sourced ground truth



Community Software



Supercomputer

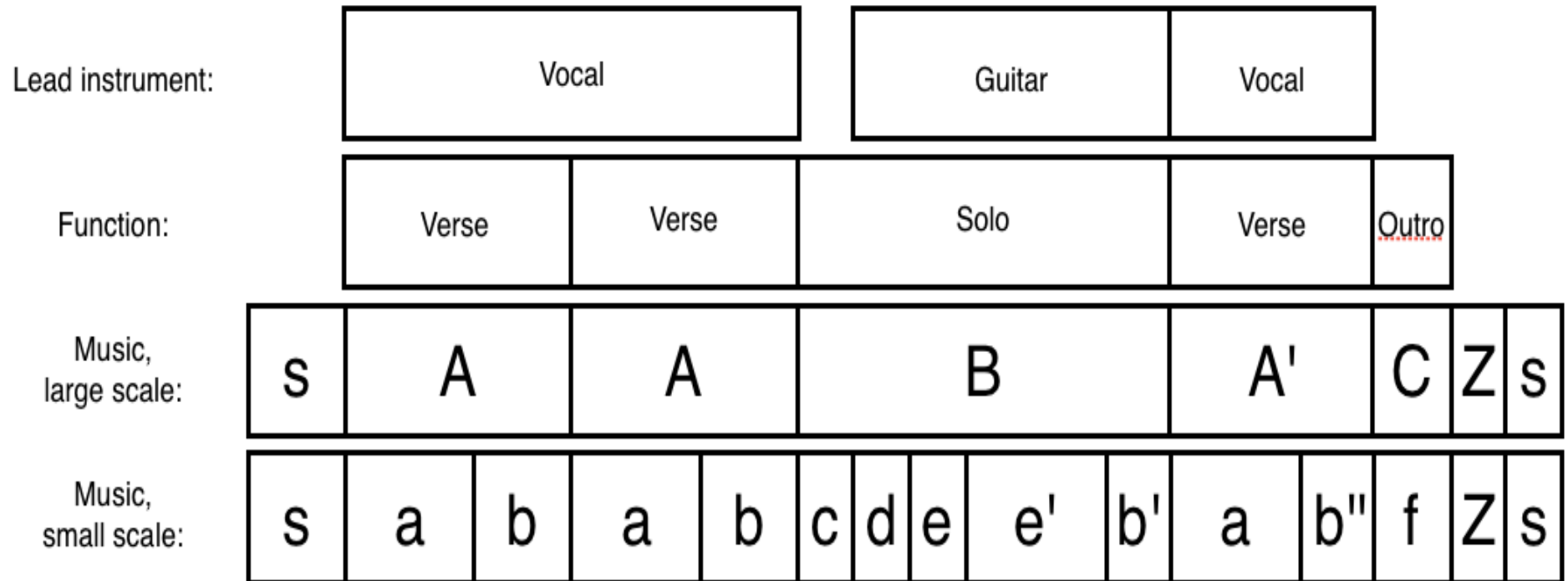
Linked Data Repositories

0.00000000	silence
0.429569160	C, c, intro
4.109951972	A, a, verse, (vocal
7.783401360	b
15.153628117	a
18.890045351	b'
26.284988662	B, d, chorus
33.523809523	e
40.857528344	A, a, verse
44.563242630	b
52.006893424	a
55.805986394	b'
63.245351473	B, d, chorus
70.530612244	e
77.929659863	A, a, verse
81.653061224	b
89.042721088	a
92.834535147	b'
100.327619047	B, d, chorus
107.647709750	e
114.956190476	B, d, chorus
122.258730158	e
129.544126984	e, vocal), outro
136.434648526	silence
139.334648526	end

0.000000000	silence
0.429569160	C, c, intro
4.109931972	A, a, verse, (vocal
7.783401360	b
15.153628117	a
18.890045351	b'
26.284988662	B, d, chorus
33.523809523	e
40.857528344	A, a, verse
44.563242630	b
52.006893424	a
55.805986394	b'
63.245351473	B, d, chorus
70.530612244	e
77.929659863	A, a, verse
81.653061224	b
89.042721088	a
92.834535147	b'
100.327619047	B, d, chorus
107.647709750	e
114.956190476	B, d, chorus
122.258730158	e
129.544126984	e, vocal), outro
136.434648526	silence
139.334648526	end



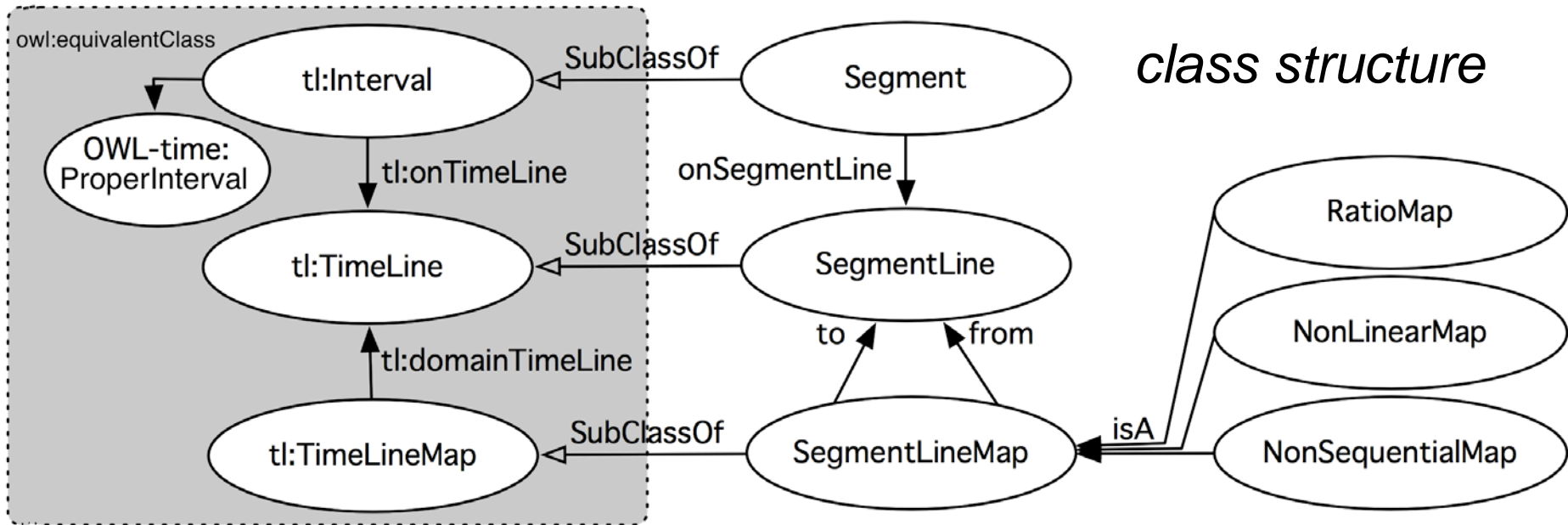
# SONIC VISUALISER



Jordan B. L. Smith, J. Ashley Burgoyne, Ichiro Fujinaga, David De Roure, and J. Stephen Downie. 2011. Design and creation of a large-scale database of structural annotations. In Proceedings of the International Society for Music Information Retrieval Conference, Miami, FL, 555–60



# Segment Ontology



Ontology models properties from musicological domain

- Independent of Music Information Retrieval research and signal processing foundations
- Maintains an accurate and complete description of relationships that link them

# Music Information Retrieval Evaluation eXchange



## MIREX TASKS

Audio Artist Identification	Audio Onset Detection
Audio Beat Tracking	Audio Tag Classification
Audio Chord Detection	Audio Tempo Extraction
Audio Classical Composer ID	Multiple F0 Estimation
Audio Cover Song Identification	Multiple F0 Note Detection
Audio Drum Detection	Query-by-Singing/Humming
Audio Genre Classification	Query-by-Tapping
Audio Key Finding	Score Following
Audio Melody Extraction	Symbolic Genre Classification
Audio Mood Classification	Symbolic Key Finding
Audio Music Similarity	Symbolic Melodic Similarity

[www.music-ir.org/mirex](http://www.music-ir.org/mirex)

## Structural Segmentation - MIREX '09

SubID	Participants	MIREX 09 F-measure	MIREX 10 RWC/Quaero SB@3sec	MIREX 10 RWC/RWC F-measure	Salami F-measure
SMGA1	Joan Serrà, Meinard Müller, Peter Grosche, Josep Lluís Arcos	0.65	0.77	0.68	0.58
SMGA2	Joan Serrà, Meinard Müller, Peter Grosche, Josep Lluís Arcos	0.63	0.76	0.69	0.53
KSP3	Florian Kaiser, Thomas Sikora, Geoffroy Peeters	0.57	0.66	0.60	0.53
MHRAF1	Benjamin Martin, Pierre Hanna, Matthias Robine, Julien Allali, Pascal Ferraro	0.56	0.54	0.58	0.57
KSP1	Florian Kaiser, Thomas Sikora, Geoffroy Peeters	0.55	0.66	0.60	0.50
SP1	Florian Kaiser, Thomas Sikora, Geoffroy Peeters	0.55	0.66	0.56	0.55
KSP2	Florian Kaiser, Thomas Sikora, Geoffroy Peeters	0.54	0.66	0.58	0.53
SBV1	Gabriel Sargent, Frédéric Bimbot, Emmanuel Vincent	0.51	0.63	0.54	0.46
OYZS1	Nobutaka Ono, Shinya Yaku, Yuko Zou, Shigeki Sagayama	0.46	0.53	0.51	0.50

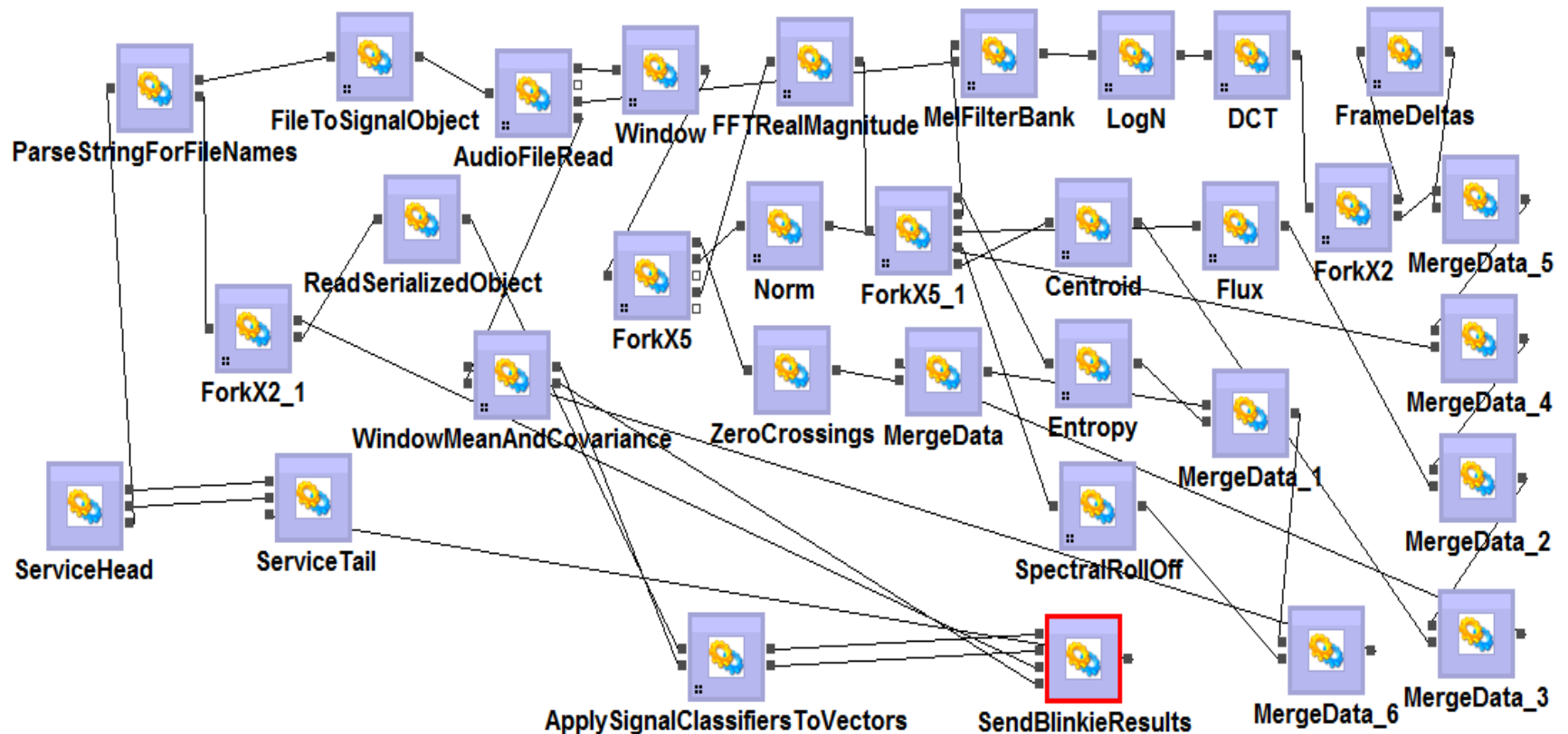
# Meandre

seasr.org/meandre



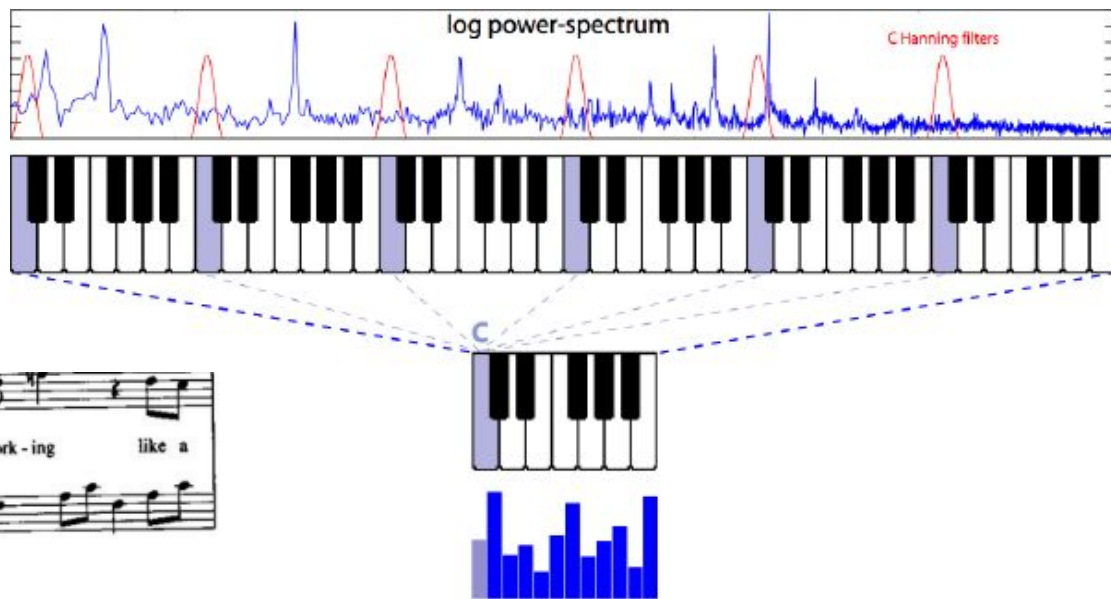
meandre

FLOW: blinkieDemo





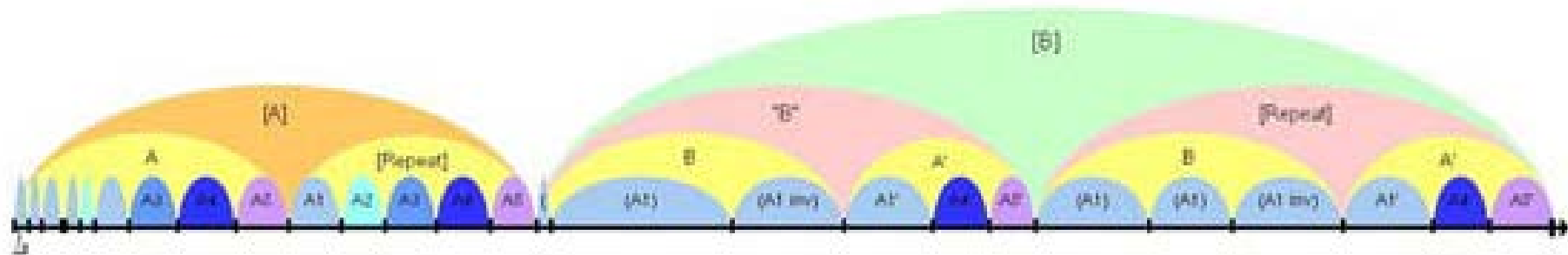
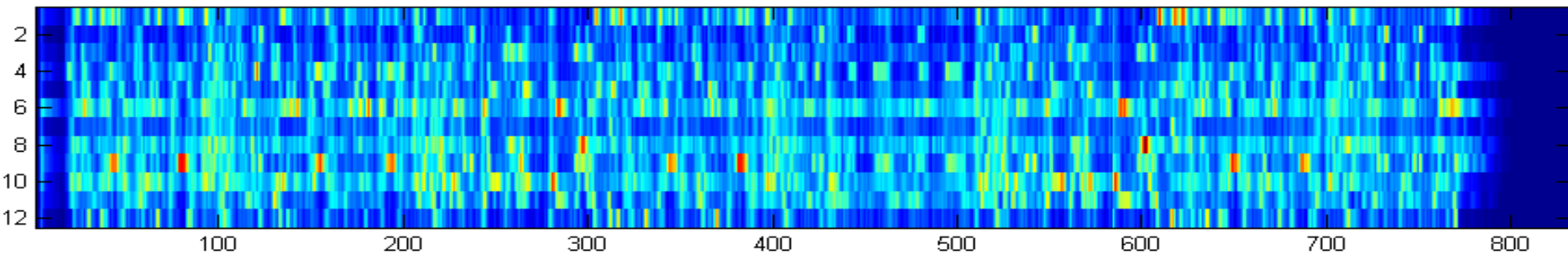
# Representations



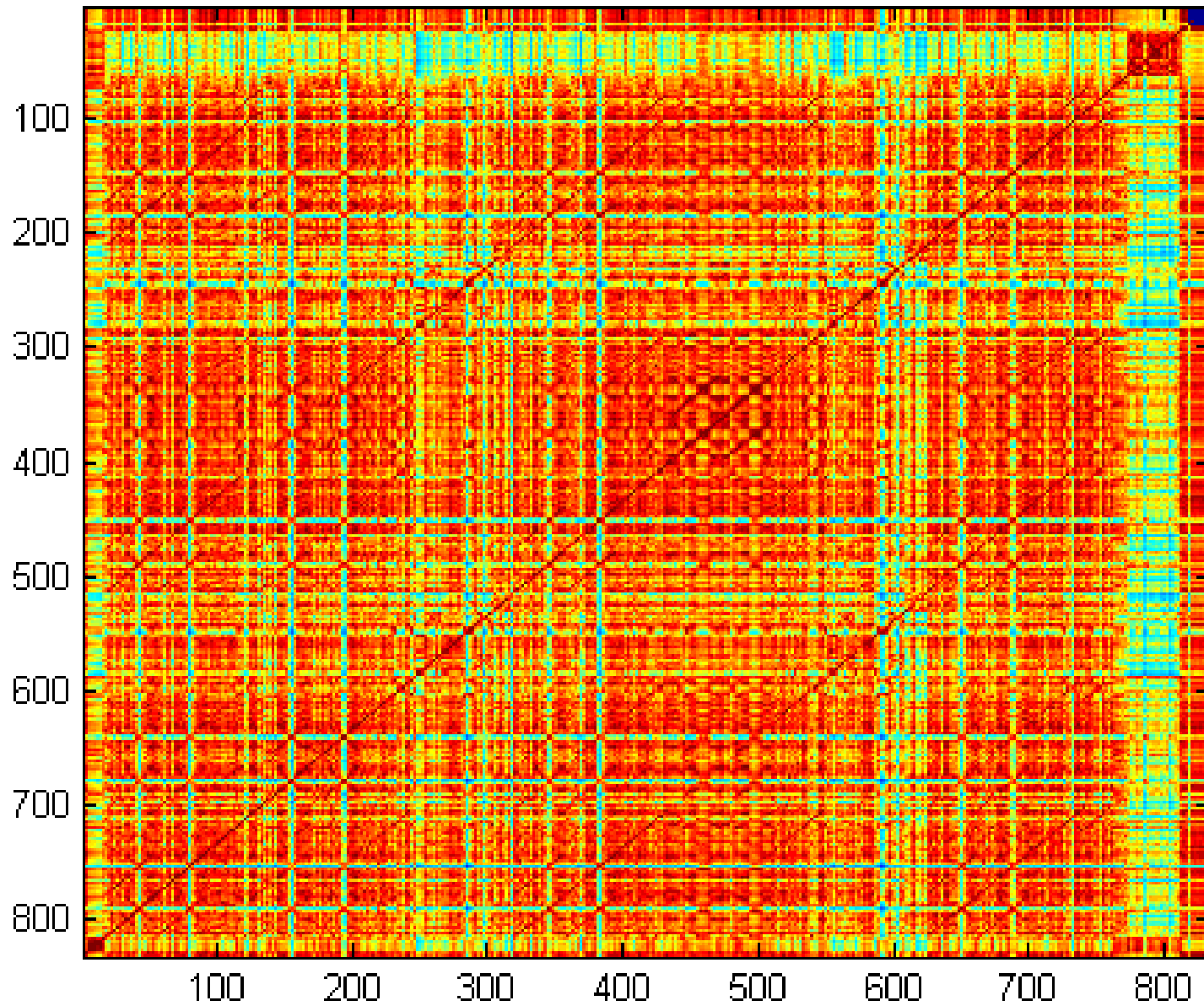
symbolic



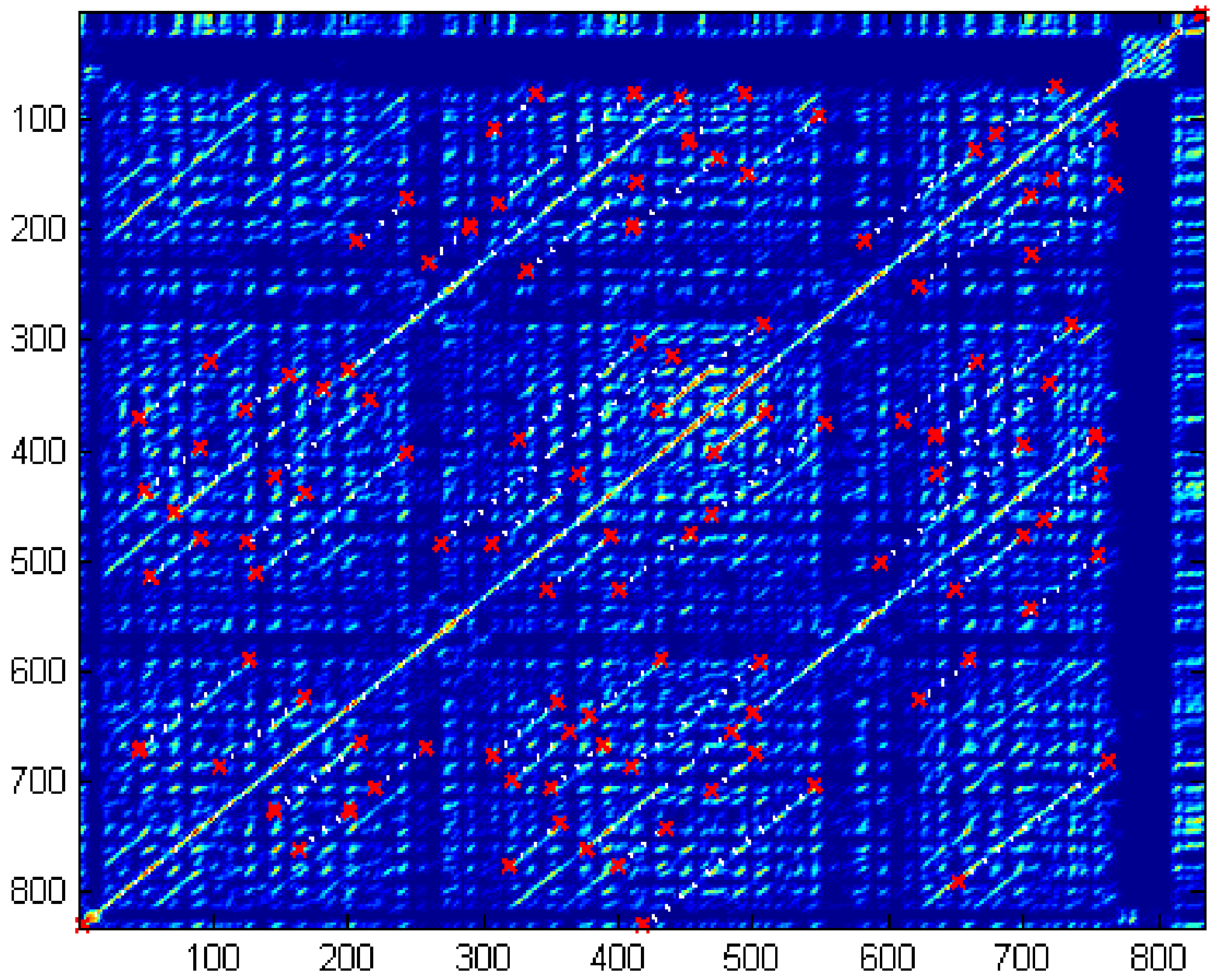
chromogram



Chroma Self-Similarity Map



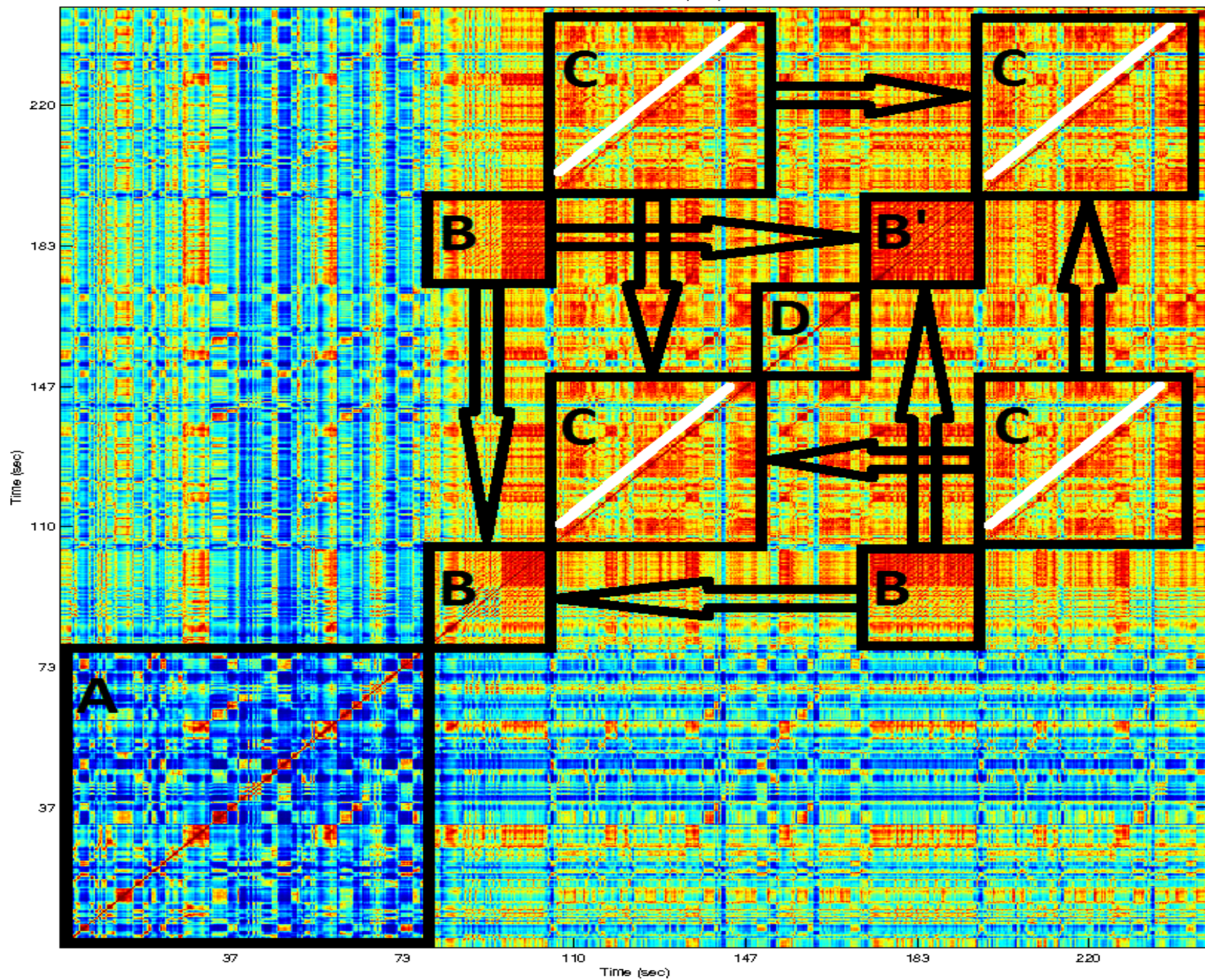
Hard Day's Night: Self-Similarity Map



Hard Day's Night: Enhanced Self-Similarity Map



Chroma Self-Similarity Map





## A Hard Day's Night

ground truth segmentation



automatic segmentation



chord correct using auto seg.



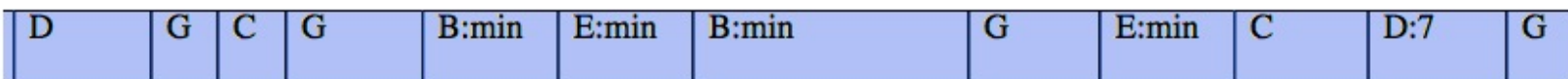
chord correct baseline meth.



0 50 100 150  
time/s

## Analysing chord structure

ground truth chords



auto chords using auto seg.



auto chords baseline meth.



40 42 44 46 48 50 52 54 56 58 60



### Kraken XT5

Cray Linux Environment  
3.1

Peak performance: 1.17  
PF

Compute cores: 112,896

Compute memory: 147 TB

Disk space: 3.3 PB

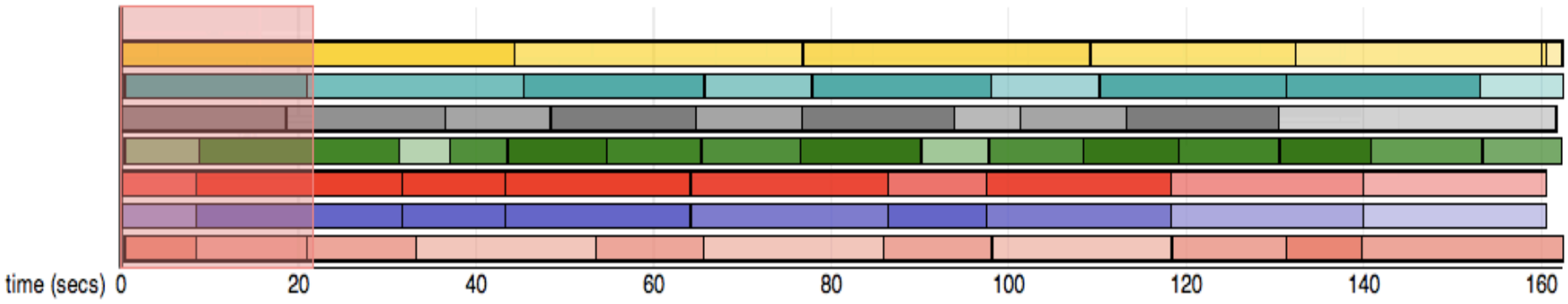
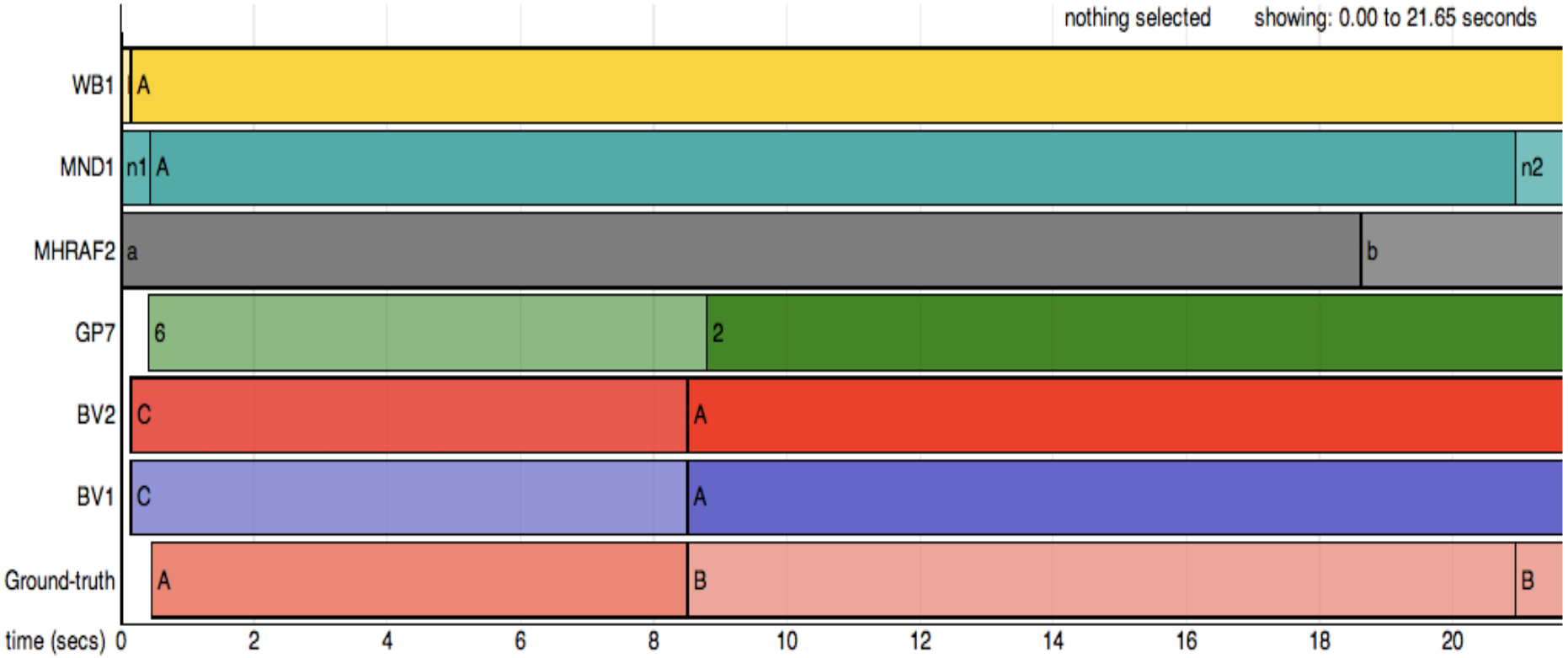
Compute nodes: 9,408

Interconnect: Cray

SeaStar2+



nothing selected showing: 0.00 to 21.65 seconds



Stephen Downie



# Michelle

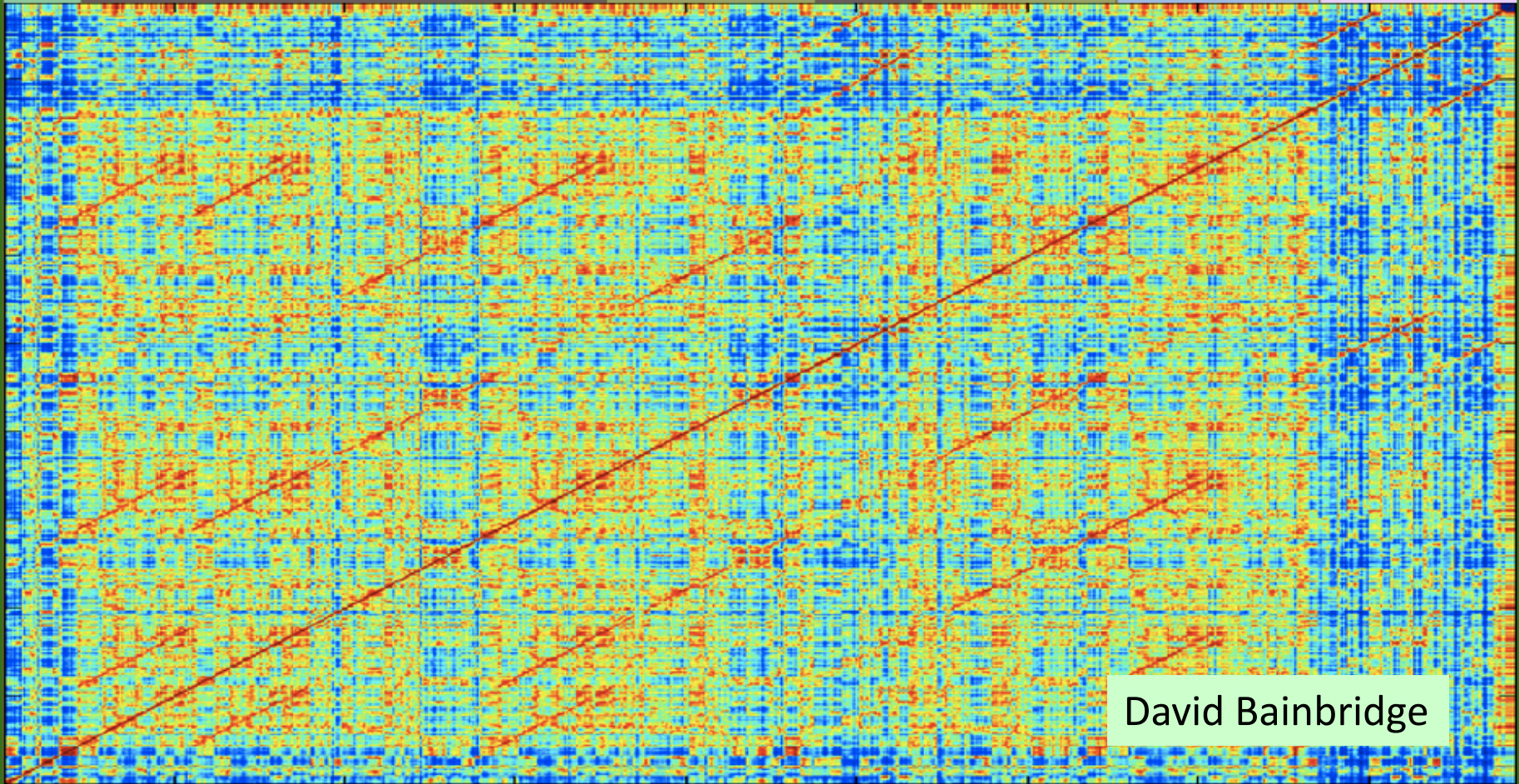
 titles 

[text search](#) [form search](#) [advanced search](#) [audio search](#)

Track Artists

Play all of: Michelle

A ▶ 🔍	B ▶ 🔍	B ▶ 🔍	C ▶ 🔍	B ▶ 🔍	C ▶ 🔍	B ▶ 🔍	C ▶ 🔍	B ▶ 🔍	A ▶ 🔍	B ▶ 🔍
C ▶ 🔍	A ▶ 🔍	A ▶ 🔍	A ▶ 🔍	B ▶ 🔍	A ▶ 🔍	B ▶ 🔍	D ▶ 🔍	E ▶ 🔍		



David Bainbridge





Summary Comparison Classical Jazz Live Popular World Help

### Summary Legend

Submission code	Submission name
BV1	Sargent et al.
BV2	Sargent et al._Config2
GP7	Ircasummary
MHRAF2	Simbals_Structure
MND1	Music Editor's Structural Segmentation
WB1	siplca-segmentation

Abstract PDF Contributors  
 PDF Gabriel Sargent, Frederic Bimbot, Emmanuel Vincent

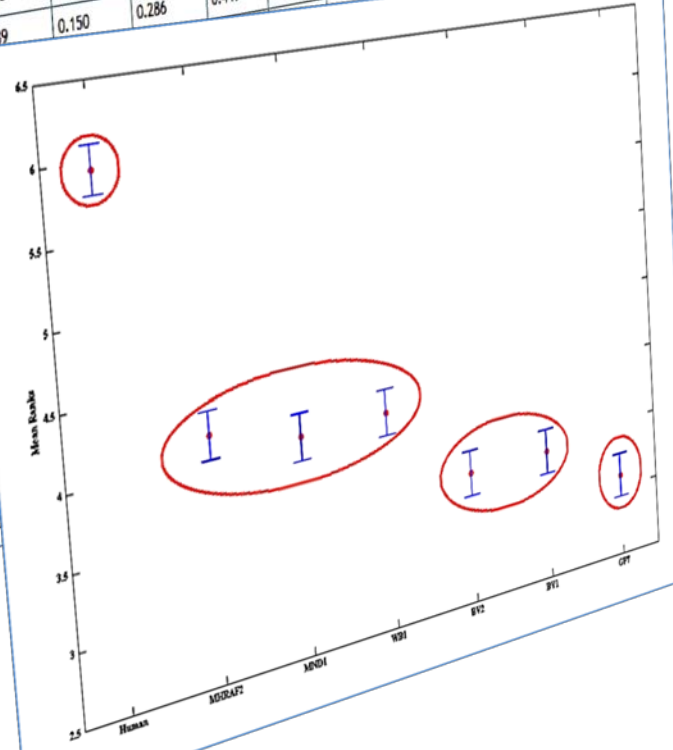
### 3. Evaluation

(a) Algorithm	NCE-OSS	NCE-USS	FPC-F	FPC-P	FPC-R	RCI	SBR-F@0.5s	SBR-P@0.5s	SBR-R@0.5s	SBR-F@3s	SBR-P@3s	SBR-R@3s	AB-2-RB	RB-2-AB
BV1	0.605	0.441	0.520	0.513	0.669	0.549	0.190	0.151	0.289	0.450	0.361	0.669	1.797	7.554
BV2	0.454	0.715	0.427	0.678	0.350	0.638	0.189	0.150	0.286	0.449	0.361	0.666	1.812	7.552
GP7	0.499	0.683	0.485	0.675	0.424	0.65								
MHRAF2	0.546	0.591	0.559	0.617	0.583	0.66								
MND1	0.624	0.625	0.556	0.649	0.586	0.66								
WB1	0.609	0.540	0.546	0.583	0.608	0.630								

(b) Algorithm	NCE-OSS	NCE-USS	FPC-F	FPC-P	FPC-R	RCI
BV1	0.643	0.323	0.384	0.321	0.680	0.505
BV2	0.521	0.567	0.373	0.452	0.386	0.712
GP7	0.584	0.557	0.432	0.467	0.482	0.655
MHRAF2	0.599	0.442	0.440	0.395	0.615	0.635
MND1	0.666	0.478	0.435	0.426	0.609	0.635
WB1	0.675	0.420	0.442	0.382	0.653	0.632

### Summary Results [\[top\]](#)

Algorithm	Normalised conditional entropy based over-segmentation score	Normalised conditional entropy based under-segmentation score	Frame pair cluster F-measure
GP7	0.5024	0.6758	0.4848
WB1	0.6092	0.5341	0.5413
MHRAF2	0.5503	0.5814	0.5354
MND1	0.6261	0.6188	0.5339
BV1	0.6562	0.4103	0.5161
BV2	0.5166	0.6613	0.4407

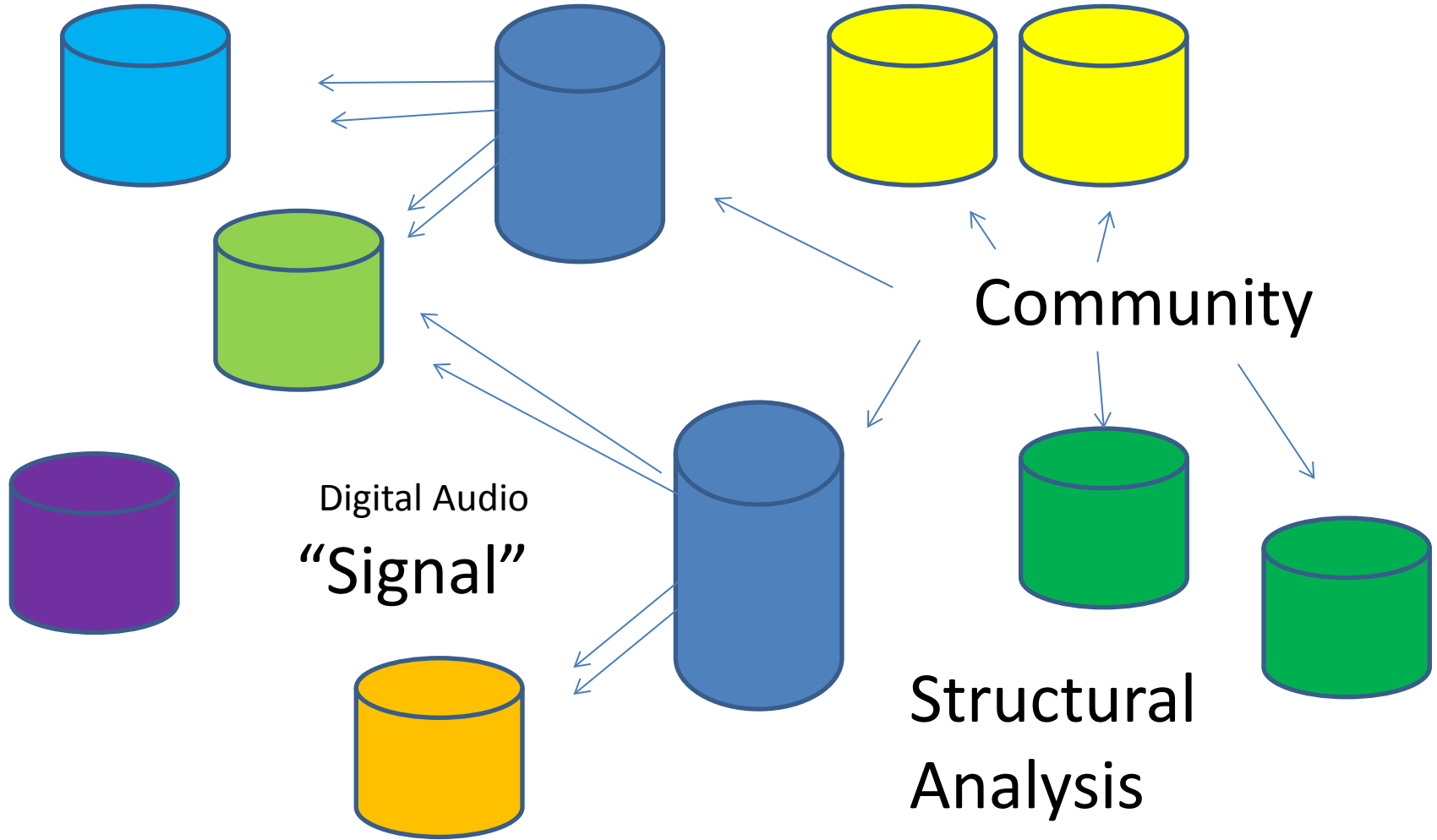


SALAMI results: a living experiment



*It's web-like!*

**“Ground Truth”**



Digital Audio  
**“Signal”**

**Community**

**Structural  
Analysis**

# Linked Data Resources

## MusicBrainz

RDF conversions of MusicBrainz data



## Geonames

Information about locations



## DBpedia

Structured representation of Wikipedia content



## BBC

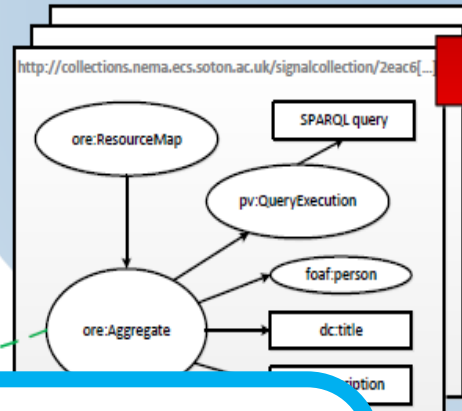
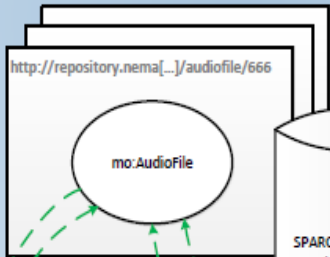
Programme information, artist information



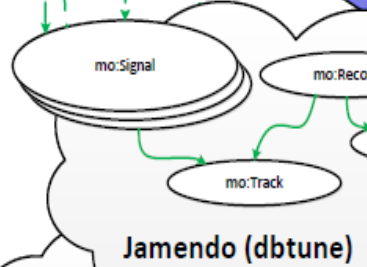
linked data resources about the signal in RDF...

e.g. a collection of tracks recorded by artists from Belgium.

...which is also imported into a triplestore to provide a SPARQL endpoint.

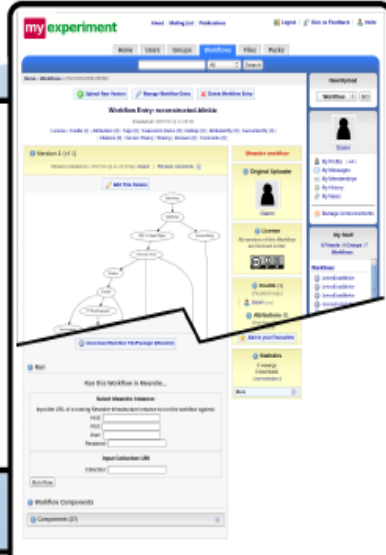


# How country is my country?



Links between linked data services form a web of data

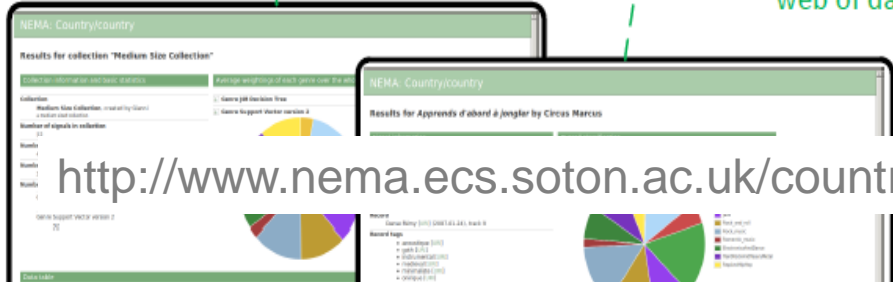
Collection metadata is passed into myExperiment, where a genre analysis workflow is selected. URIs for constituent elements of the collection are passed to the workflow...



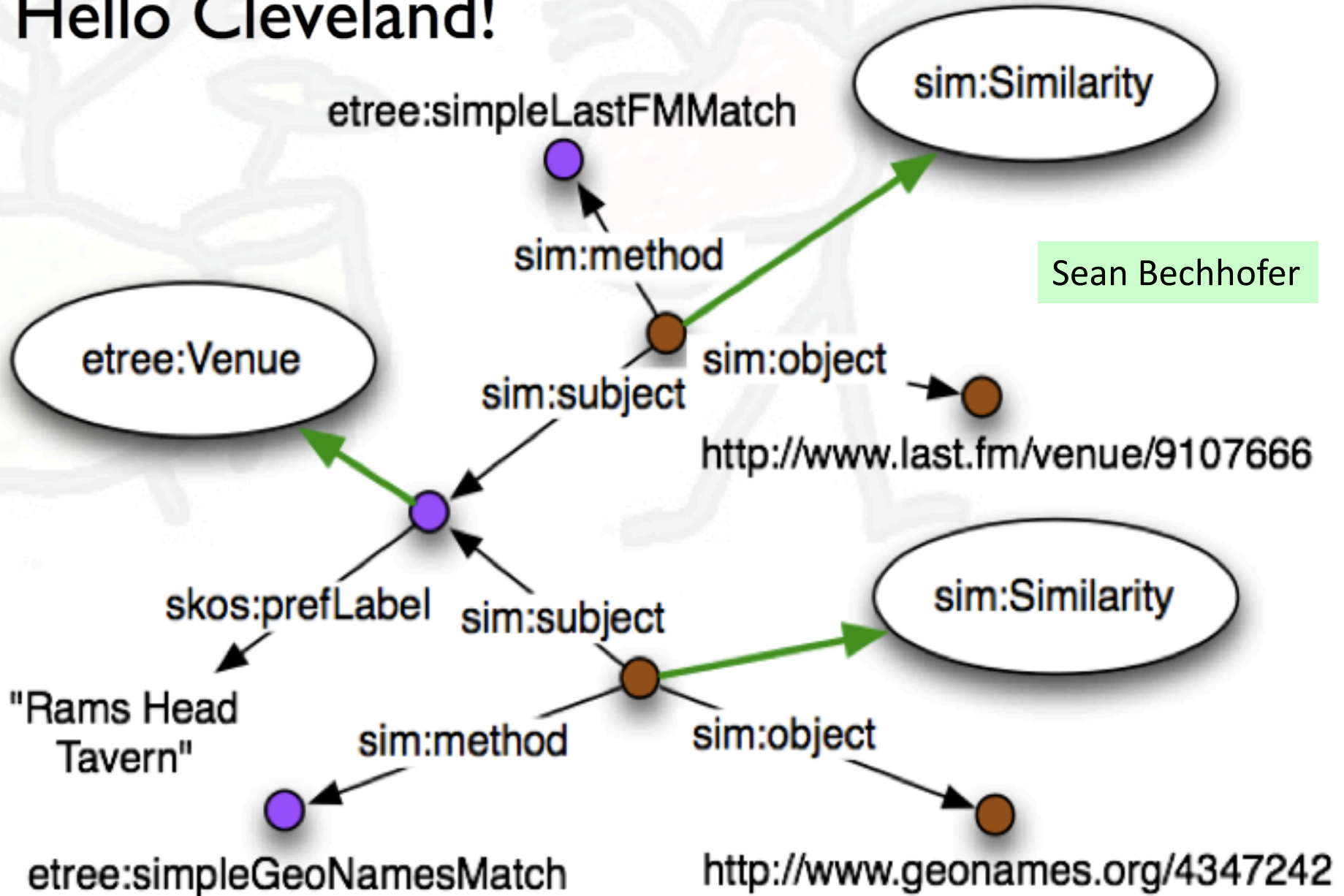
<http://www.nema.ecs.soton.ac.uk/countrycountry/>

Kevin Page and Ben Fields

...in Meandre where the genre



# Hello Cleveland!



Sean Bechhofer



# Overview

This talk is both *computational* and *social*

1. How is research done today?

- *Structural Analysis of Large Amounts of Music Information (SALAMI)* – a case study in Computational Musicology

2. What are the implications for our ‘knowledge infrastructure’?

- *Research Objects and Social Machines*

PHILOSOPHICAL  
TRANSACTIONS:  
GIVING SOME  
ACCOMPT  
OF THE PRESENT  
Undertakings, Studies, and Labours  
OF THE  
INGENIOUS  
IN MANY  
CONSIDERABLE PARTS  
OF THE  
WORLD.

Vol I.

For Anno 1665, and 1666.

In the SAVOY,  
Printed by T. N. for John Martyn at the Bell, a little with-  
out Temple-Bar, and James Allestry in Duck-Lane,  
Printers to the Royal Society.

PHILOSOPHICAL  
TRANSACTIONS  
OF

THE ROYAL  
SOCIETY

A

MATHEMATICAL,  
PHYSICAL  
& ENGINEERING  
SCIENCES

## An e-Research approach to Web-scale music analysis

David De Roure, Kevin R. Page, Benjamin Fields, Tim Crawford, J. Stephen Downie and Ichiro Fujinaga

*Phil. Trans. R. Soc. A* 2011 **369**, 3300-3317  
doi: 10.1098/rsta.2011.0171

### References

[This article cites 5 articles](#)

<http://rsta.royalsocietypublishing.org/content/369/1949/3300.full.html#ref-list-1>

[Article cited in:](#)

<http://rsta.royalsocietypublishing.org/content/369/1949/3300.full.html#related-urls>

### Subject collections

Articles on similar topics can be found in the following collections

[e-science](#) (43 articles)

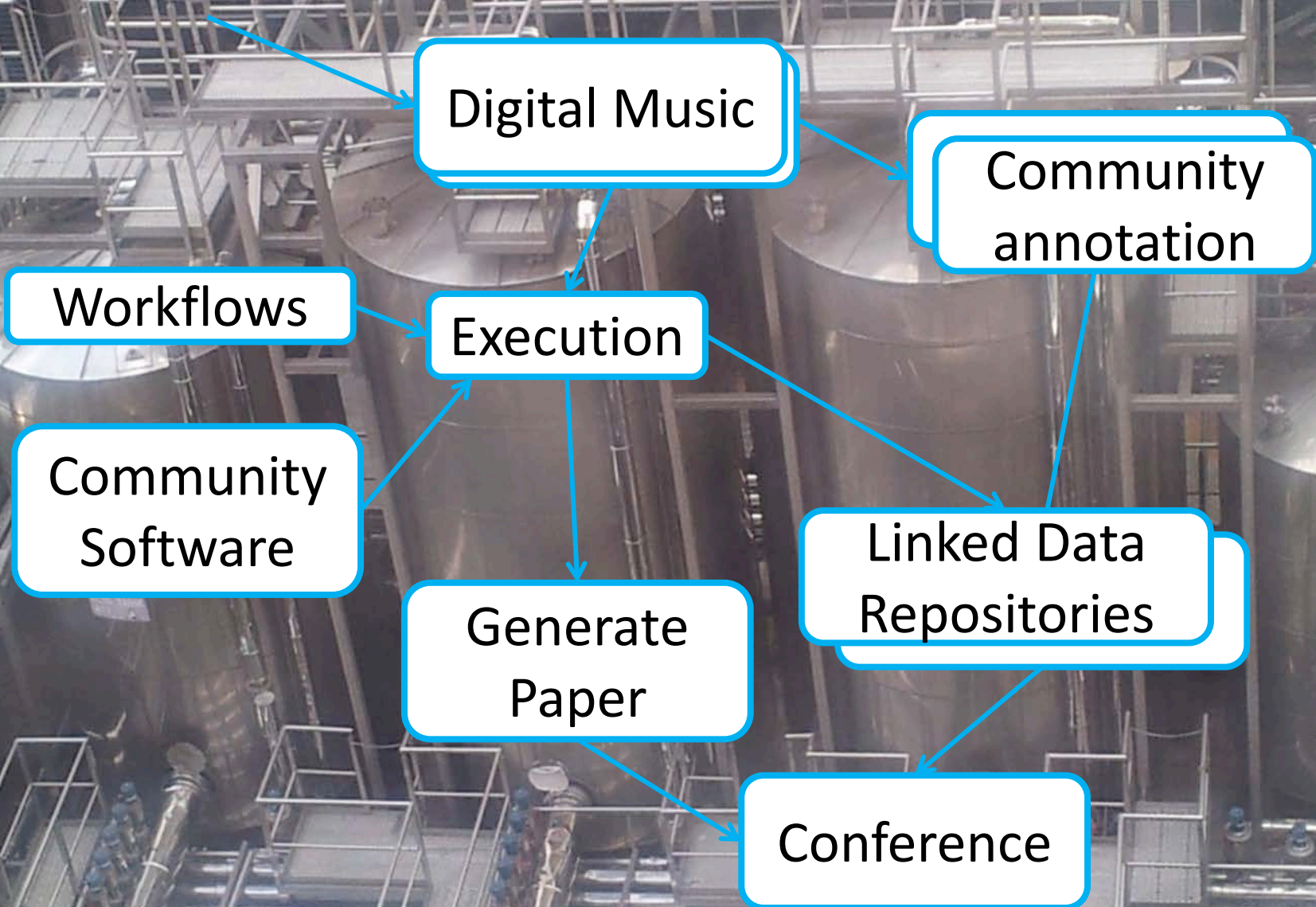
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# Information Circuits





# Notifications and automatic re-runs

Autonomic  
Curation

Self-repair

New research?

Jun Zhao et al, "Why Workflows Break - Understanding and Combating Decay in Taverna Workflows", IEEE eScience 2012, Chicago

Khalid Belhajjame et al "Workflow-Centric Research Objects: First Class Citizens in Scholarly Discourse", SePublica2012 at ESWC2012, Greece, May 2012

Belhajjame, Goble, Soiland-Reyes, De Roure. Fostering Scientific Workflow Preservation Through Discovery of Substitute Services. IEEE eScience 2011, Stockholm

*Machines are users too*





### How do galaxies form?

NASA's Hubble Space Telescope

### Explore the surface of the Moon

**ZOONIVERSE**  
REAL SCIENCE ONLINE

GALAXY ZOO      MOON ZOO



### Hear Whales communicate

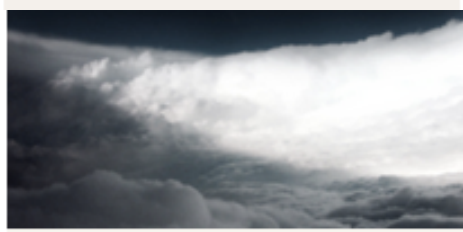
You can help marine researchers understand what whales are saying

### Help explore the ocean floor

The HabCam team and the Woods Hole Oceanographic Institution need your help!

WHALE EYE

SEAFLOOR EXPLORER



### Model Earth's climate using historic ship logs

Help scientists recover Arctic

### Classify over 30 years of tropical cyclone data.

Scientists at NOAA's National

**HANNY**  
and the Mystery  
of the Voorwerp

writing by  
Mike Beatini, Pamela L. Gay,  
Bill Keel, Kelly McCullough,  
Mike Schoenberg, and  
Jason & Jodi Thibeault

edited by  
Kelly McCullough &  
Pamela L. Gay

line art by  
Elea Braasch

colorist and letterer  
Chris Spangler

A Project of the  
**ZOONIVERSE**  
<http://hannysvoorwerp.zooniverse.org>

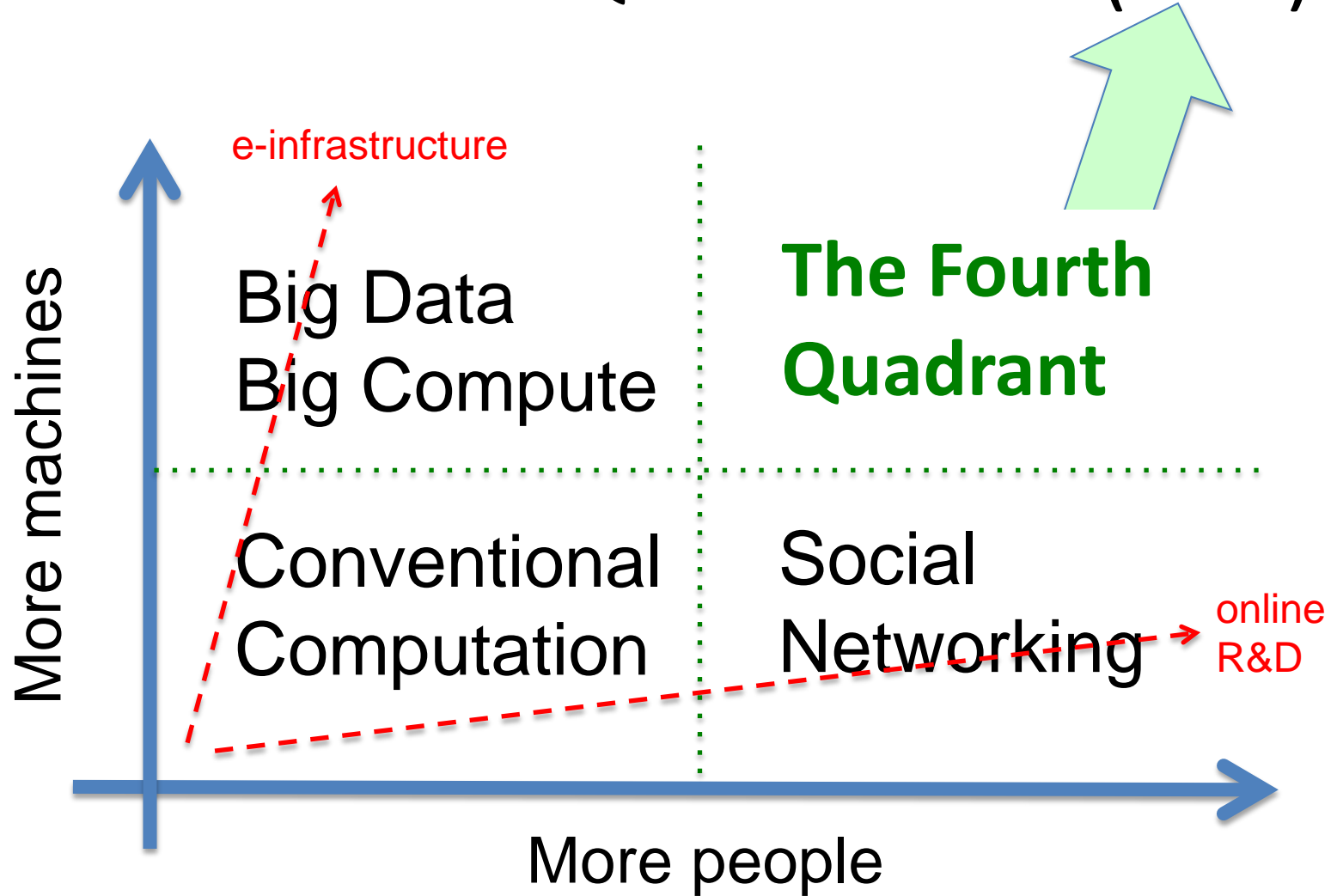
### Greeks

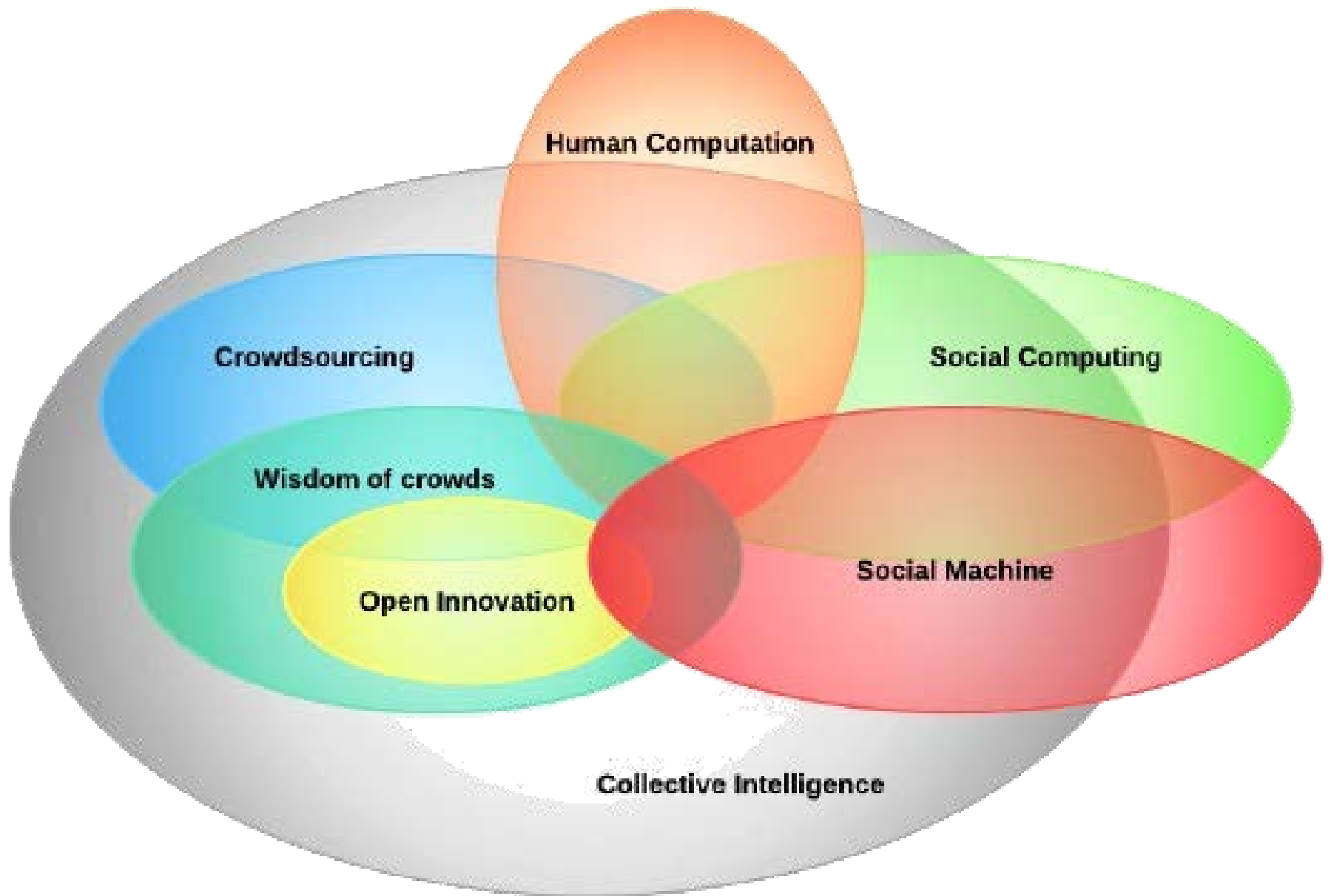
The data gathered by Ancient

### data.

You can help scientists from the

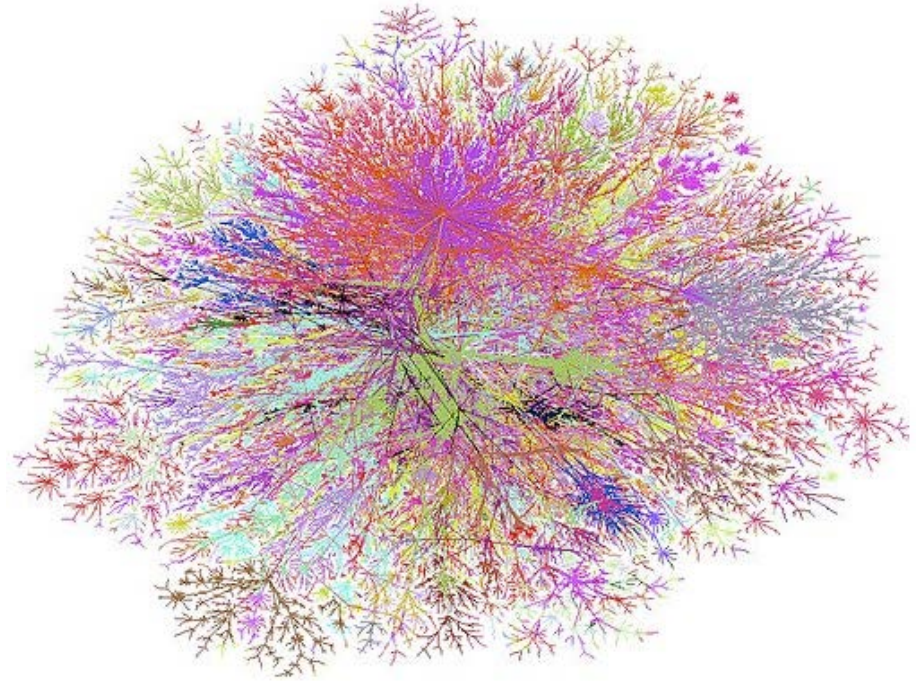
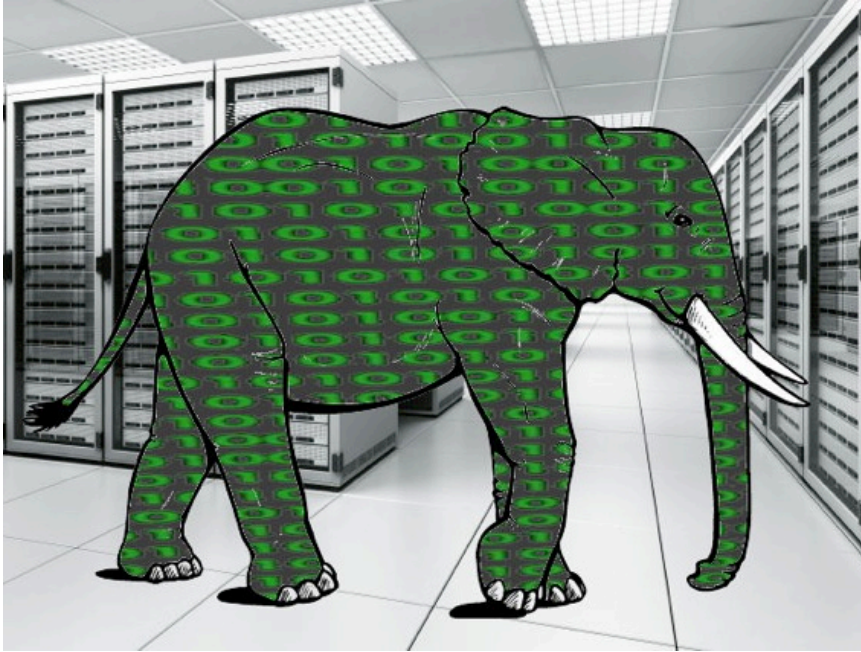
# This is a Fourth Quadrant Talk (still!)







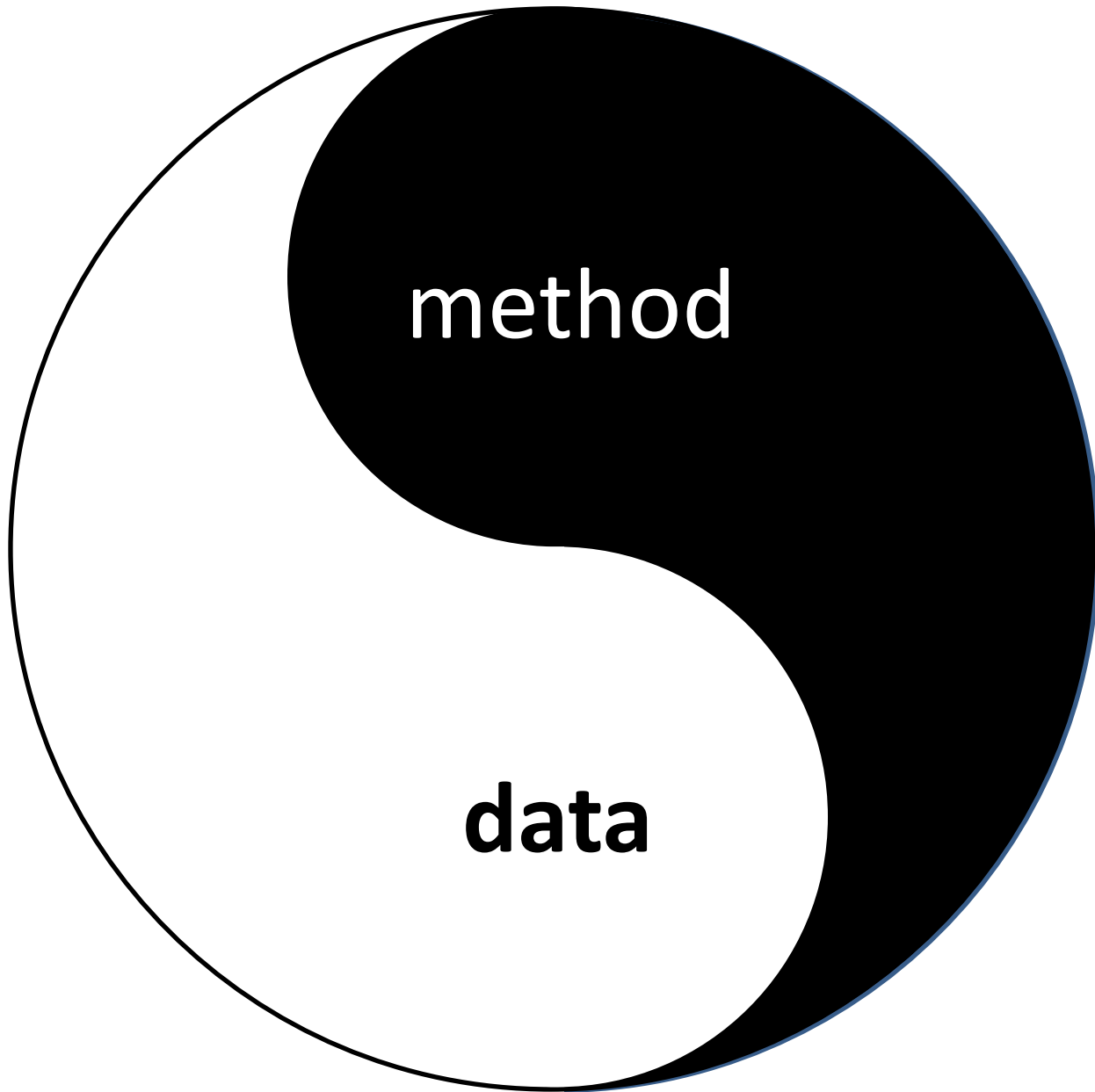
# Big data elephant versus sense-making network?



The challenge is to foster the co-constituted socio-technical system on the right i.e. a computationally-enabled sense-making network of expertise, data, models and narratives.

This requires a “social machines” perspective from the outset as well as humanistic input. The Web, and with it Web Science, are an important exemplar.





method

data

### Workflow Entry: Success-Abandonment-Classification

Created at: 06/02/08 @ 14:35:41 Last updated: 02/07/08 @ 17:15:25

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Version 3 (latest) (of 3) View version: 3 (latest)

Version created on: 06/02/08 @ 14:35:41 by: Andrea Wiggins | Revision comments

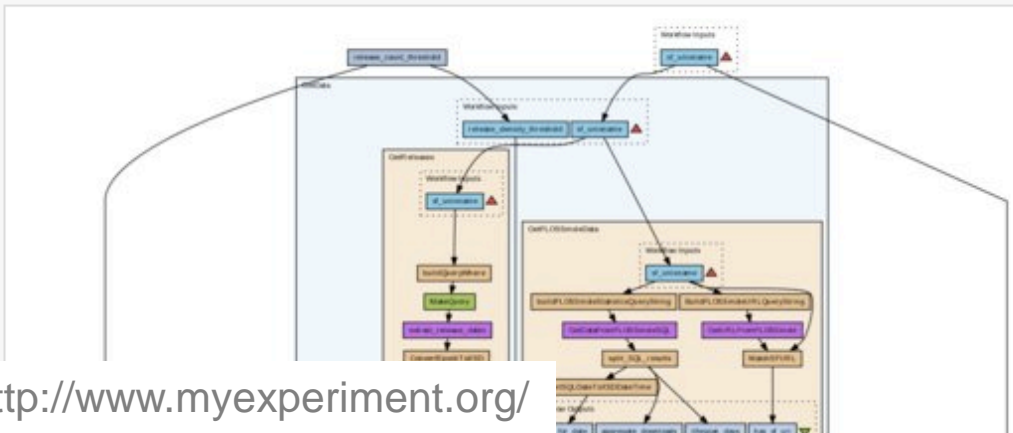
Last edited on: 02/07/08 @ 17:15:25 by: Andrea Wiggins

Title: Success-Abandonment-Classification

Type: Taverna 1

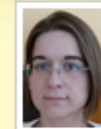
#### Preview

(Click on the image to get the full size)



Workflow Type Taverna 1

Original Uploader



Andrea Wiggins

License

All versions of this Workflow are licensed under:



Credits (2)

(People/Groups)

Andrea Wiggins

James Howison

Attributions (0)

#### New/Upload

Workflow GO



David De Roure

- My Profile [edit]
- My Messages (3)
- My Memberships (1)
- My History
- My News

Manage Announcements

#### 3 new messages

- Hi David
- Sean Bechhofer is n...
- Invitation to 'Wf4E...

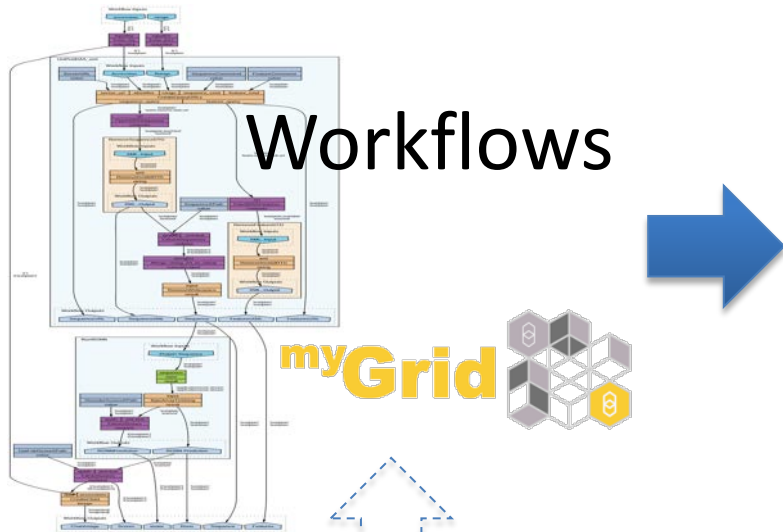
#### 2 new friendship requests

- Yehia El-khatib
- mihailonita\_me

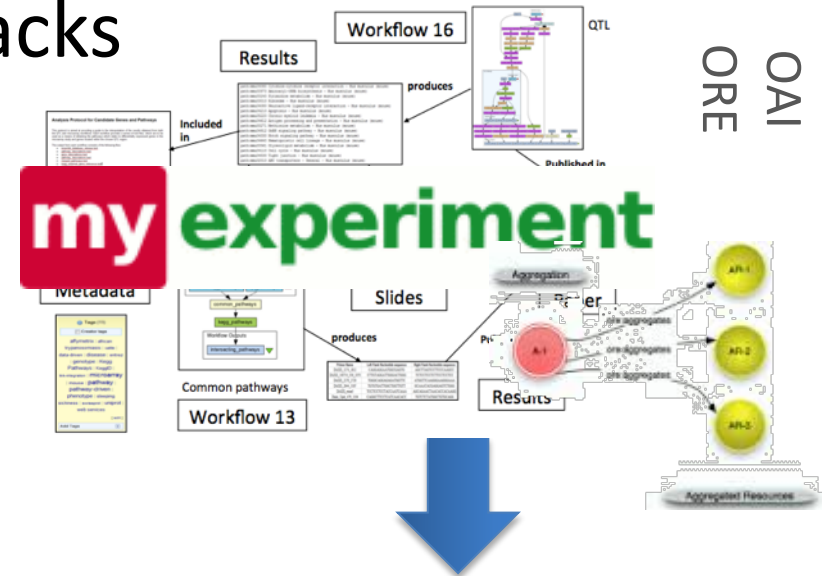
#### 1 new group request

- From Pique (for Group: Wf4Ever)

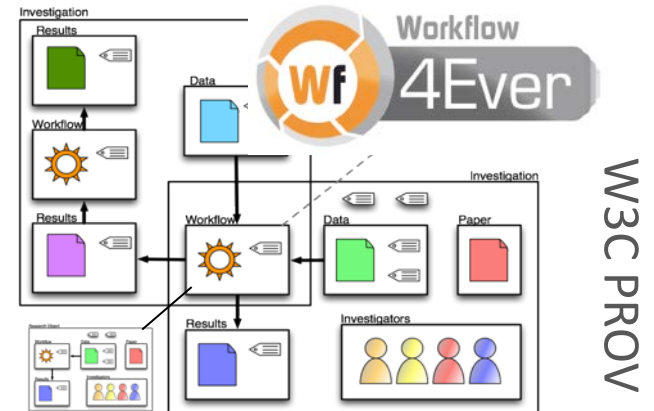
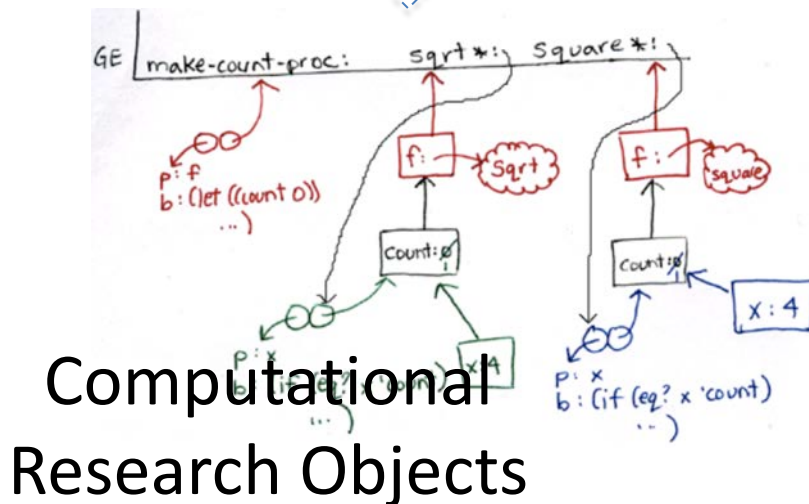
# Evolving the myExperiment Social Machine



Packs



Research Objects



# The R dimensions



**Reusable.** The key tenet of Research Objects is to support the sharing and reuse of data, methods and processes.

**Repurposeable.** Reuse may also involve the reuse of constituent parts of the Research Object.

**Repeatable.** There should be sufficient information in a Research Object to be able to repeat the study, perhaps years later.

**Reproducible.** A third party can start with the same inputs and methods and see if a prior result can be confirmed.

**Replayable.** Studies might involve single investigations that happen in milliseconds or protracted processes that take years.

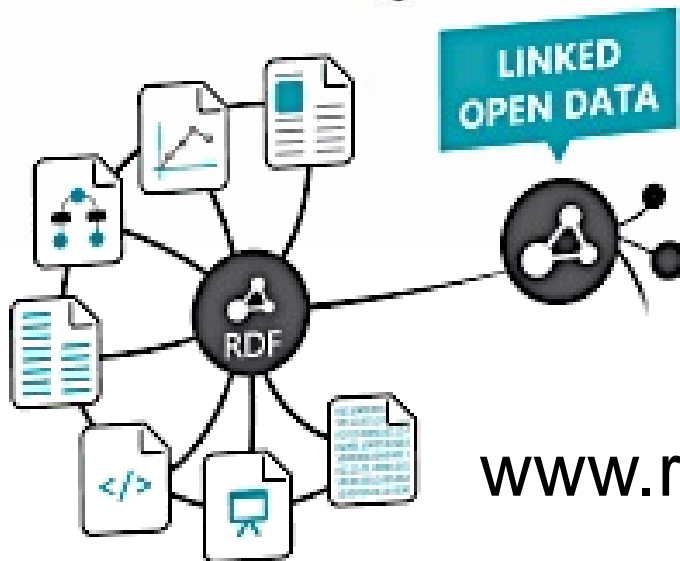
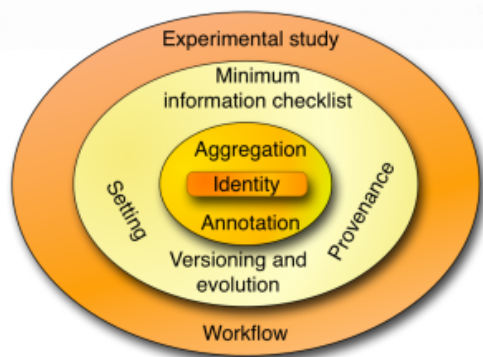
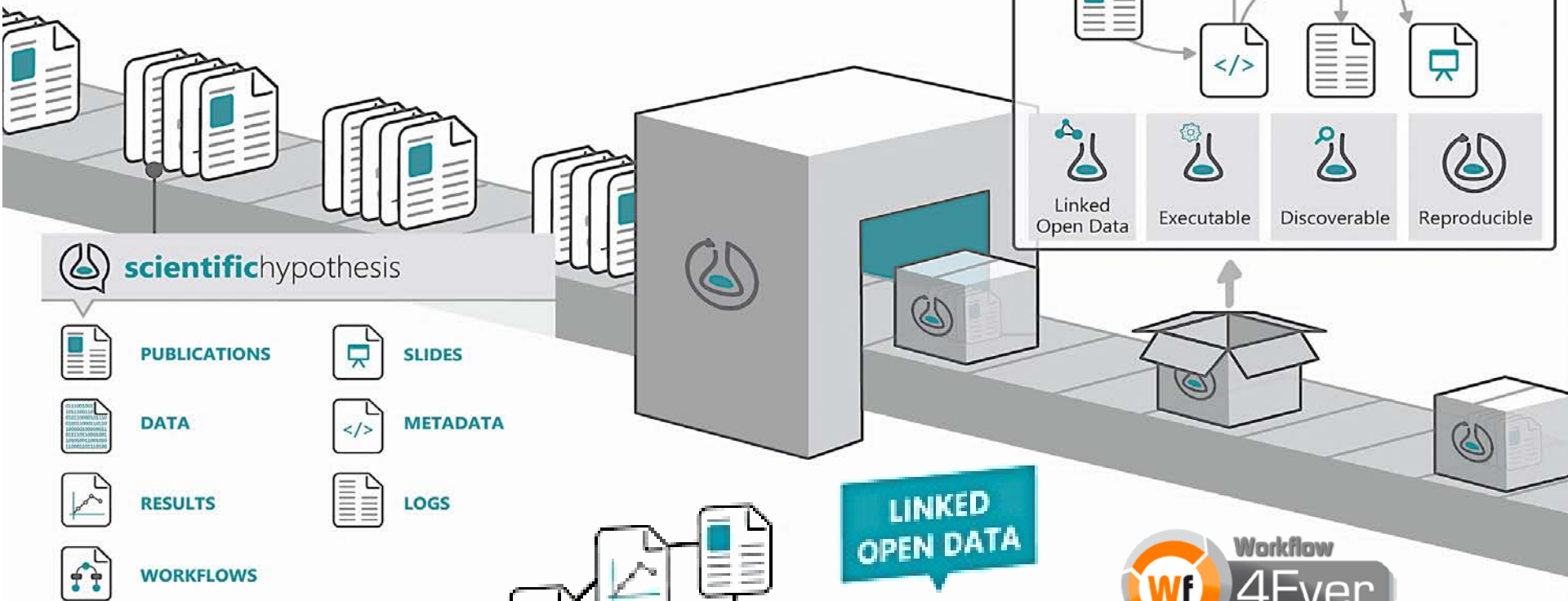
**Referenceable.** If research objects are to augment or replace traditional publication methods, then they must be referenceable or citeable.

**Revealable.** Third parties must be able to audit the steps performed in the research in order to be convinced of the validity of results.

**Respectful.** Explicit representations of the provenance, lineage and flow of intellectual property.



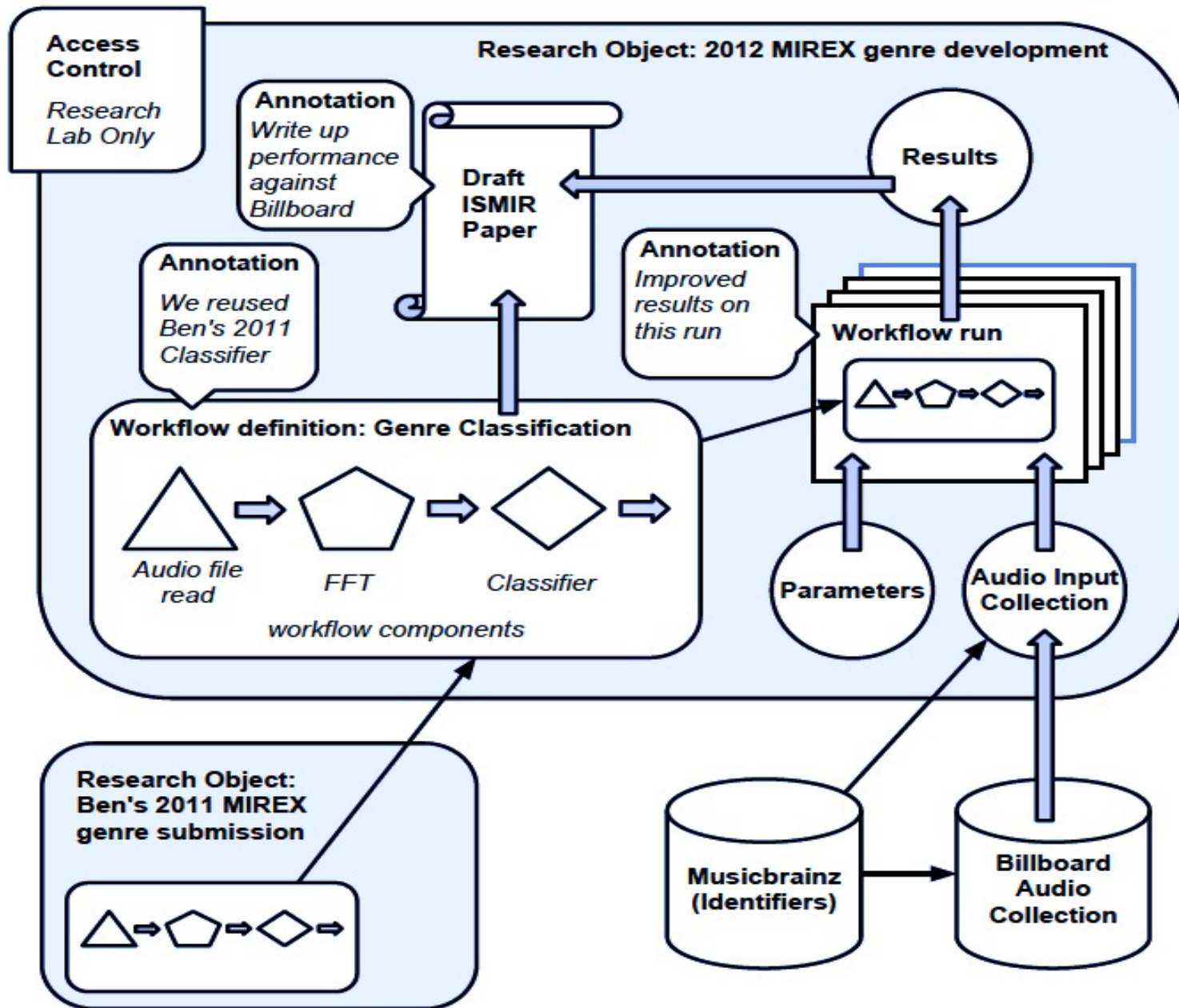
Enabling **reproducible**, transparent research.



Jun Zhao

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# Online sustain evaluation

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## The Software Sustaina

Software is not static. New functionality is needed, evolves, staff come and go and sources of funding survive in this volatile environment, software developers respond to changes and act to ensure that their software from their software.

The Software Sustainability Institute can help ensure your software. We will work with your project and expertise in software development, project management, community building to further your research.

### Recent notes

**SoundSoftware 2013: Second Workshop on Software and Data for Audio and Music Research**

The second one-day workshop on Software and Data for Audio and Music Research will take place on 26 June 2013. The aim of this workshop is to discuss issues such as robust software development for audio and music research, reproducible research, management of research data, and open access.

**Announcing our first Call For Software Projects**

Could your research work benefit from assistance or expertise to improve its long-term sustainability and reusability?

## SoundSoftware.ac.uk Prizes for Reproducibility in Audio and Music Research

To promote the development and release of sustainable and reusable software associated with published research, the SoundSoftware project will be awarding a number of "Reproducible Research Prizes". If you have published your software or datasets as part of your audio or music research output, so that other UK researchers can reproduce your results, you could win a prize!

### News

- 19 May 2013: Submissions closed
- 23 Apr 2013: Initial announcement

### Categories

1. Journal paper: New submission

# The Order of Social Machines

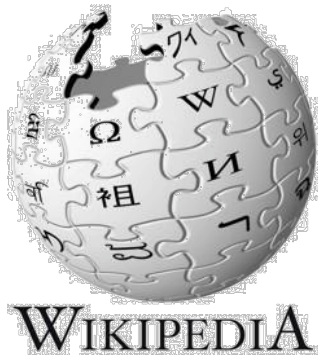
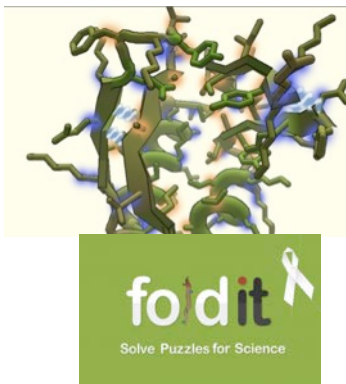
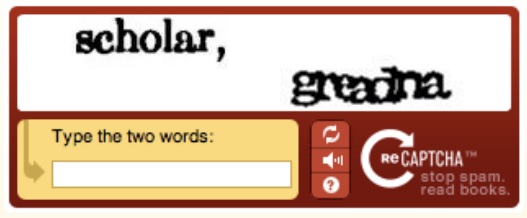
Real life is and must be full of all kinds of social constraint – the very processes from which society arises. Computers can help if we use them to create abstract social machines on the Web: processes in which the people do the creative work and the machine does the administration...

The stage is set for an evolutionary growth of new social engines.

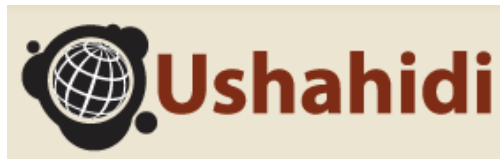
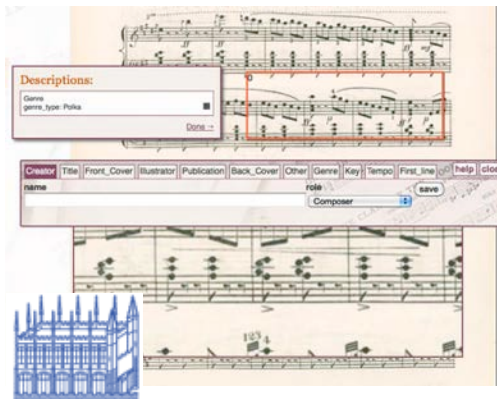
Berners-Lee, *Weaving the Web*, 1999



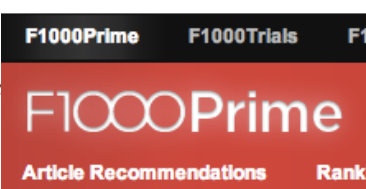
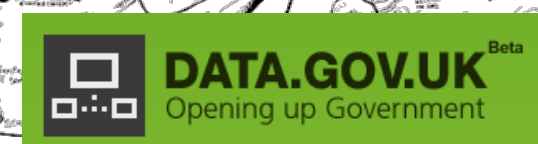
# Some Social Machines



## What's the score at the Bodleian?



DAY 1: STATE of the ART  
**BEYOND**



Scholarly Machines  
Ecosystem

FORCE 11



# Closing questions

1. Where are you going in the Fourth Quadrant?
2. What are your Research Objects - and what do computational ones look like?
3. What are the new Social Machines?

*Thanks to Stephen Downie, Ich Fujinaga, Mark Sandler and their teams, to Tim Crawford, David Bainbridge, Kevin Page, Sean Bechhofer, Ben Fields, Jun Zhao, Nigel Shadbolt, Iain Buchan, and to Carole Goble and the my{Grid,Experiment} and wf4Ever teams.*

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- SALAMI  
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- Workflow Forever project (Wf4Ever)  
<http://www.wf4ever-project.org/>
- Future of Research Communication (FORCE11)  
<http://force11.org/>
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