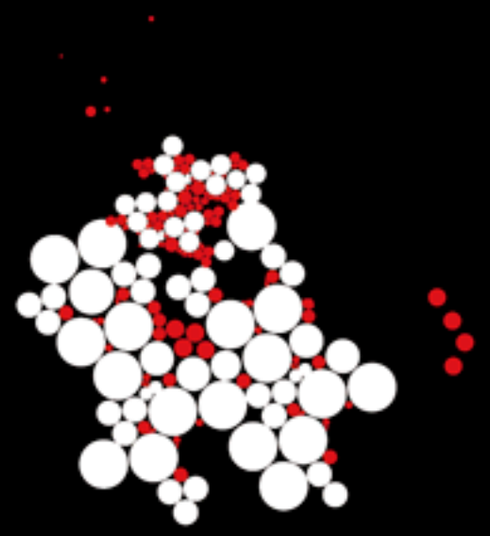
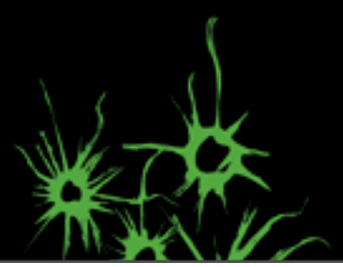
UNIVERSITY OF TWENTE.

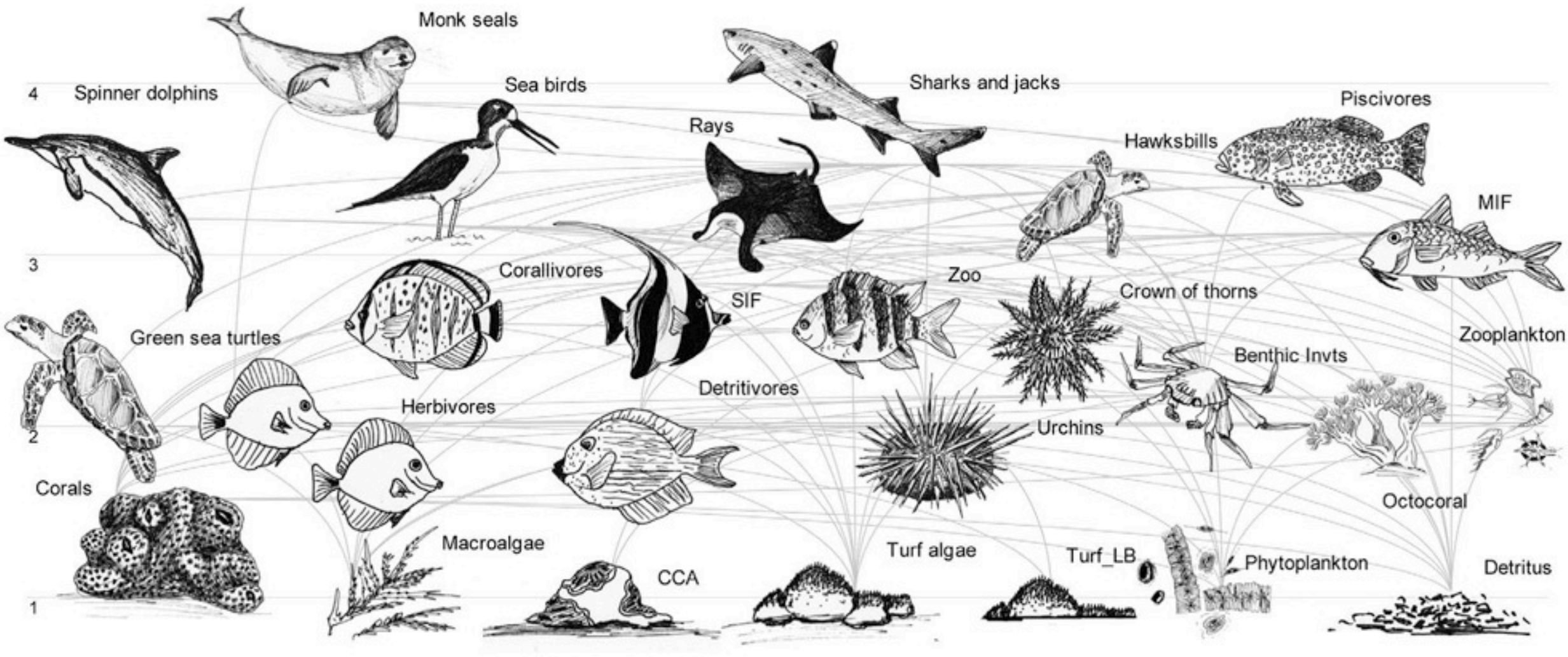


Model integration – from simple to complex, from brain to cloud

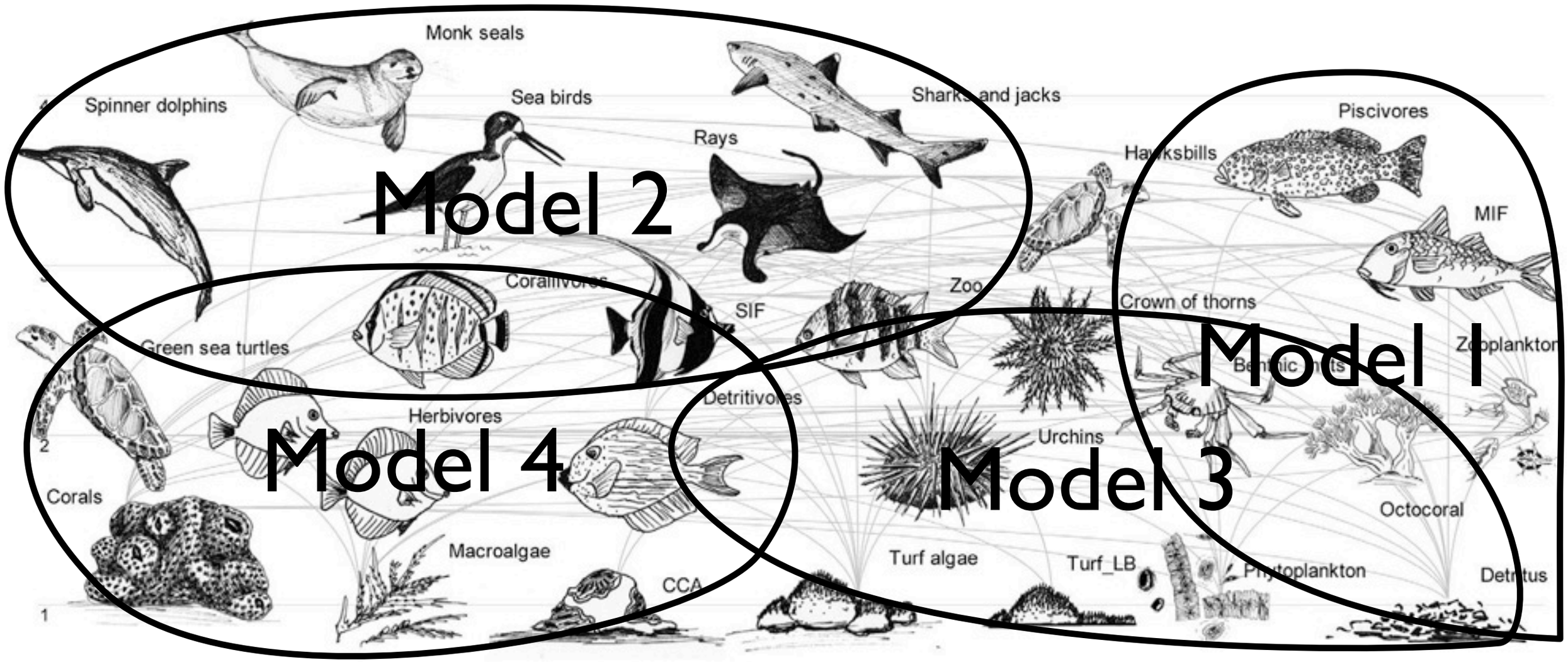
Alexey Voinov
Faculty of Geo-Information Science and Earth Observation (ITC)
University of Twente
aavoinov@gmail.com



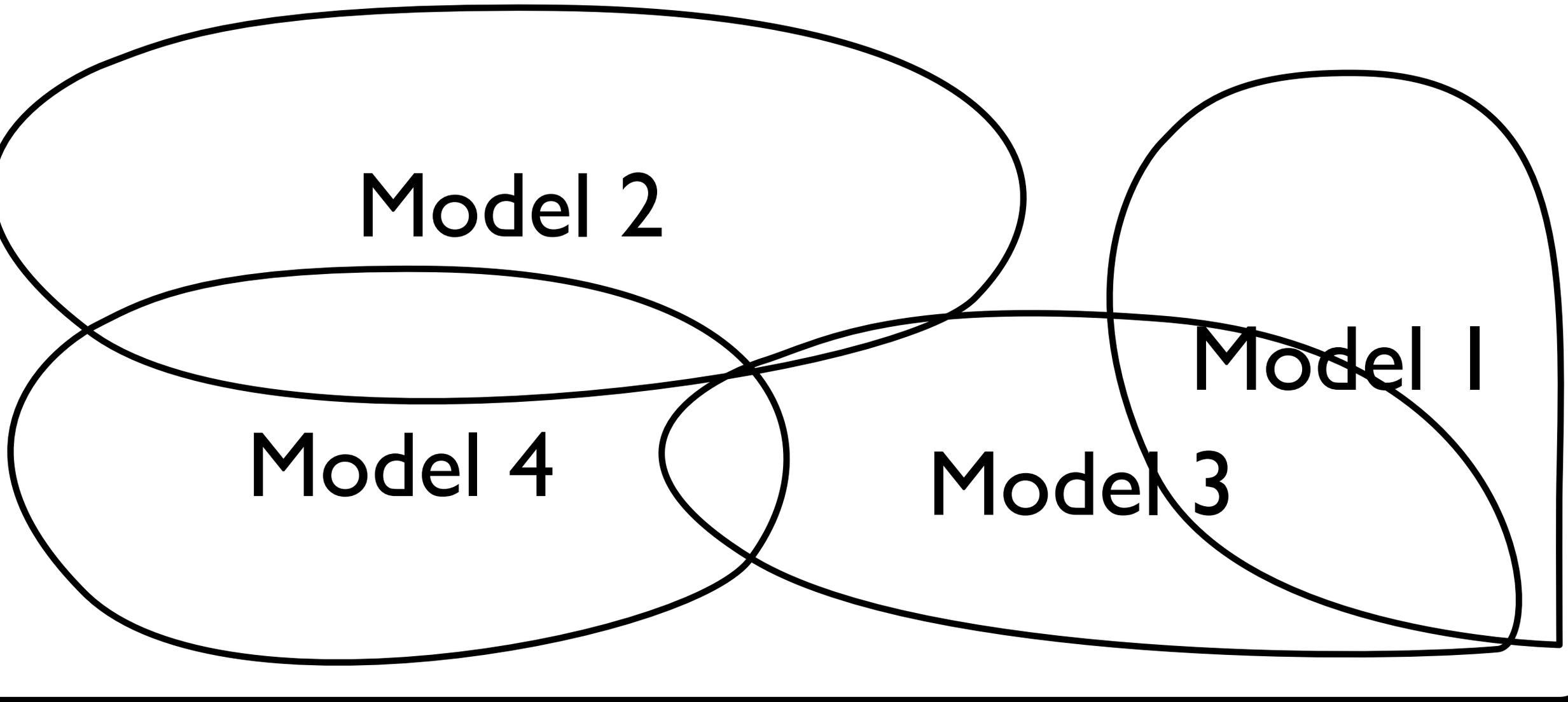
Model integration



Model integration



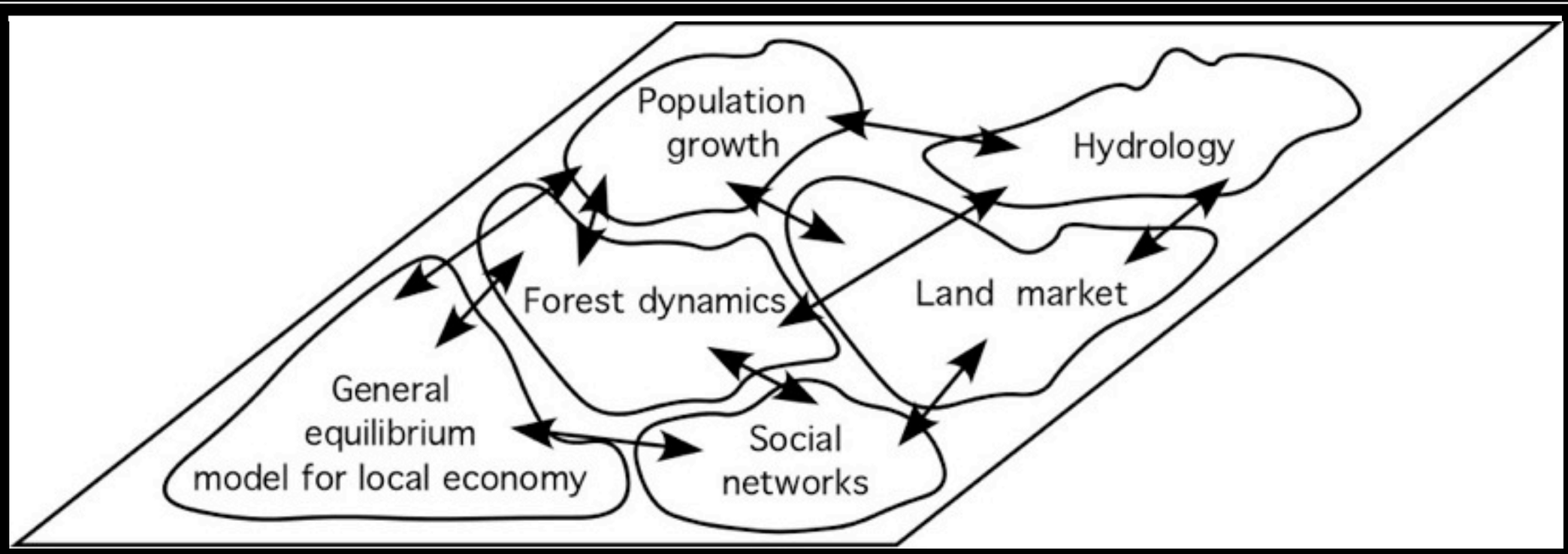
Model integration



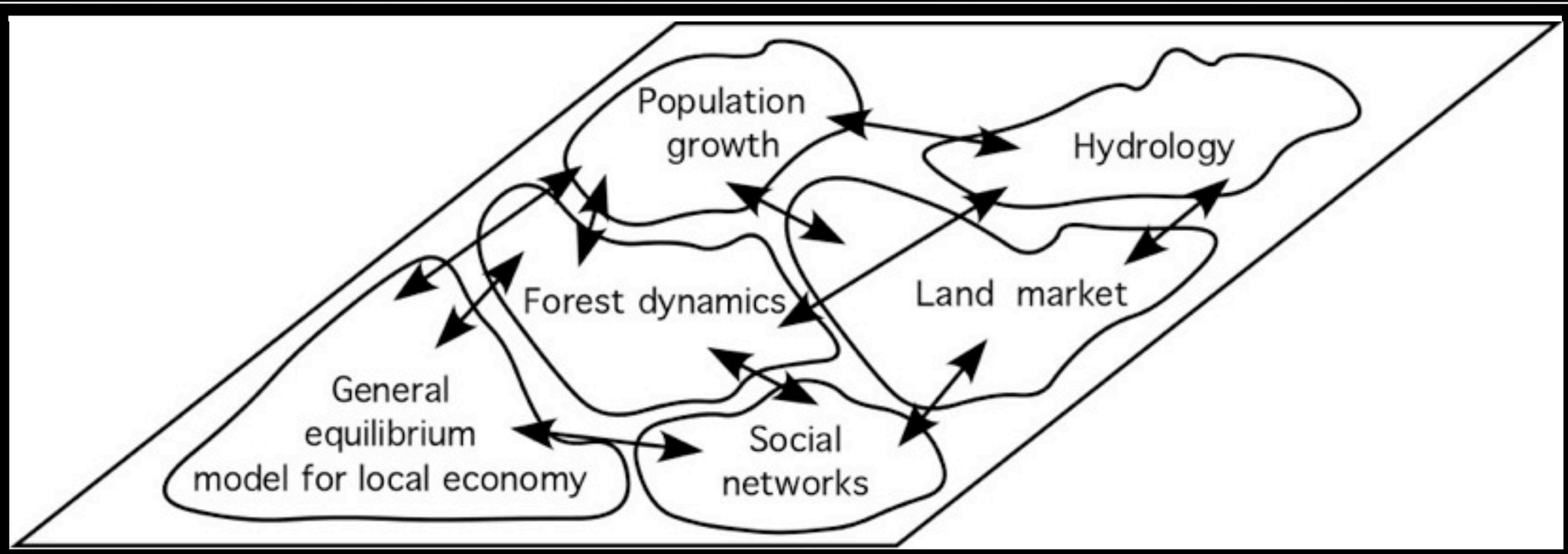
After 30+ years of modeling for decision support & environmental assessment...

- A proliferation of models
  - One model cannot be sufficient to represent all the details needed for decision making and planning
- Many legacy models developed by the “best in the field”
  - Legacy models can be reused as building blocks for more complex systems
- How do we do it?
- Reuse and integrate models

Integrated modeling



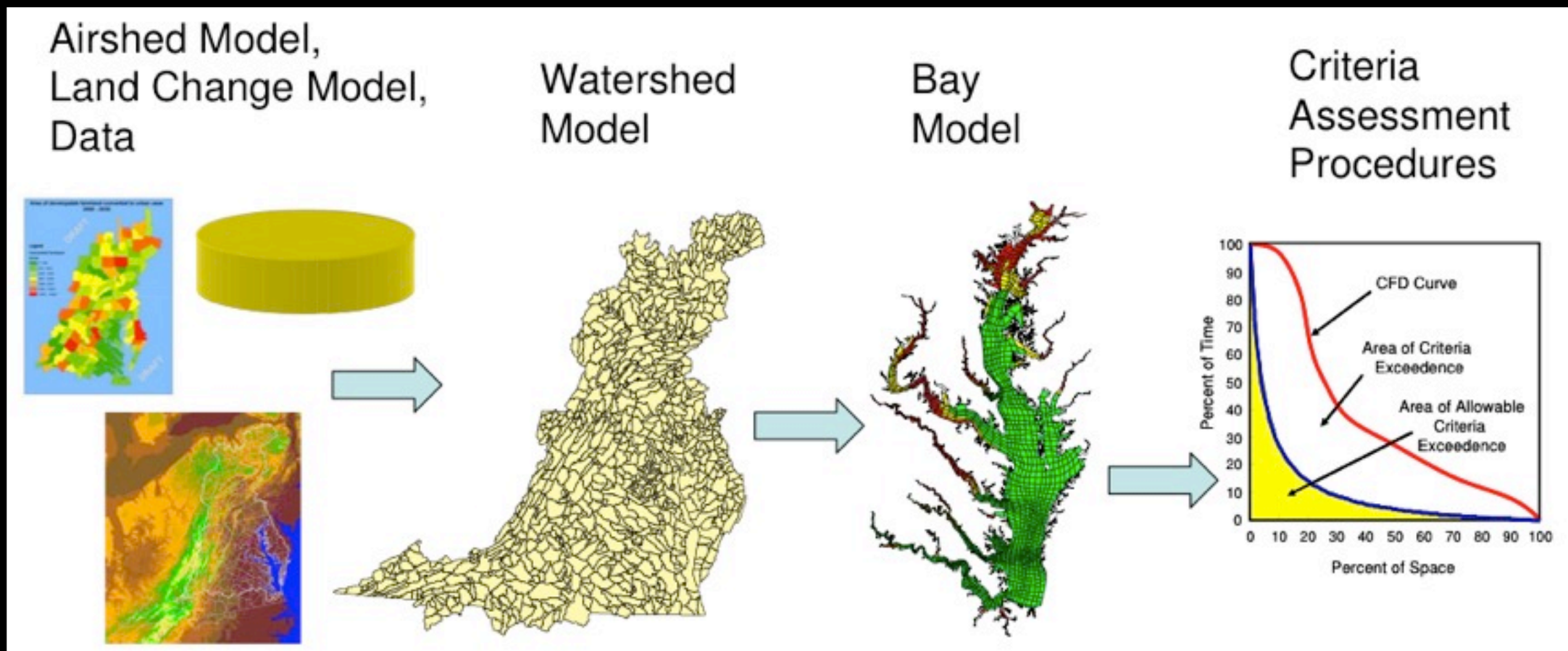
Integrated modeling



- "Integrated modeling is a systems analysis-based approach to environmental assessment. It includes a set of interdependent science based components (models, data, and assessment methods) that together form the basis for constructing an appropriate modeling system" *

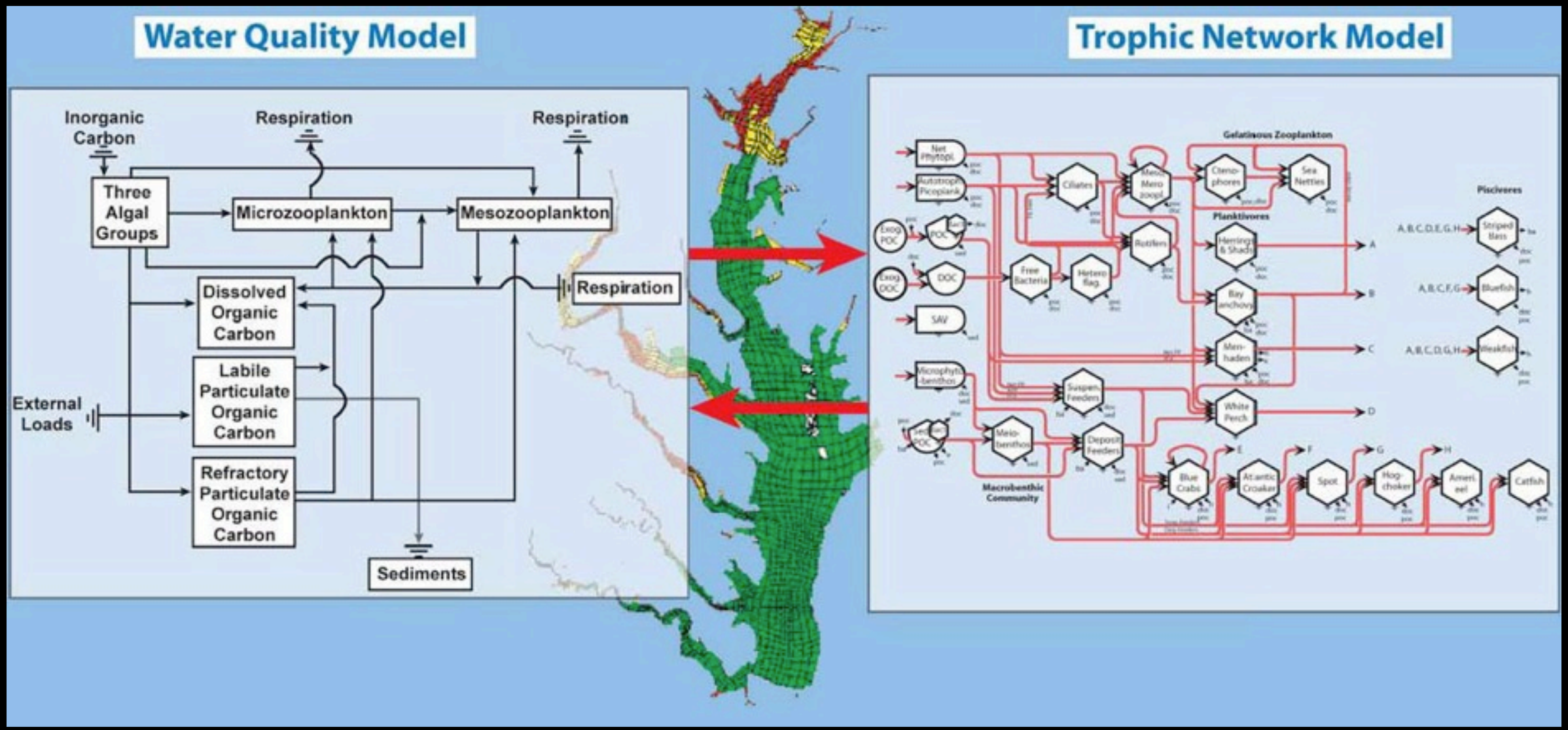
* EPA (2008). White Paper on Integrated Modeling for Integrated Environmental Decision Making: http://www.epa.gov/crem/library/IM4IEDM_White_Paper_Final_(EPA100R08010).pdf

Integrated models



- Airshed Model - 12 km grid CMAQ
- Watershed Model - 308 land segments, 17 land use types, 930 rivers running HSPF
- Water Quality and Sediment Transport Model (WQSTM) with additions of filter feeders, SAV, fish, etc.

Linkage of WQSTM to Ecopath



Model integration

- SEAMLESS - System for Environmental and Agricultural Modeling: Linking European Science and Society
  - Combining micro and macro level analysis, addressing economic, environmental and social issues, and facilitating the re-use of models and providing methods to conceptually and technically link different models
  - http://www.seamless-ip.org/

Model integration

- SEAMLESS - System for Environmental and Agricultural Modeling: Linking European Science and Society
  - Combining micro and macro level analysis, addressing economic, environmental and social issues, and facilitating the re-use of models and providing methods to conceptually and technically link different models
  - http://www.seamless-ip.org/

Problems (software angle - doable)

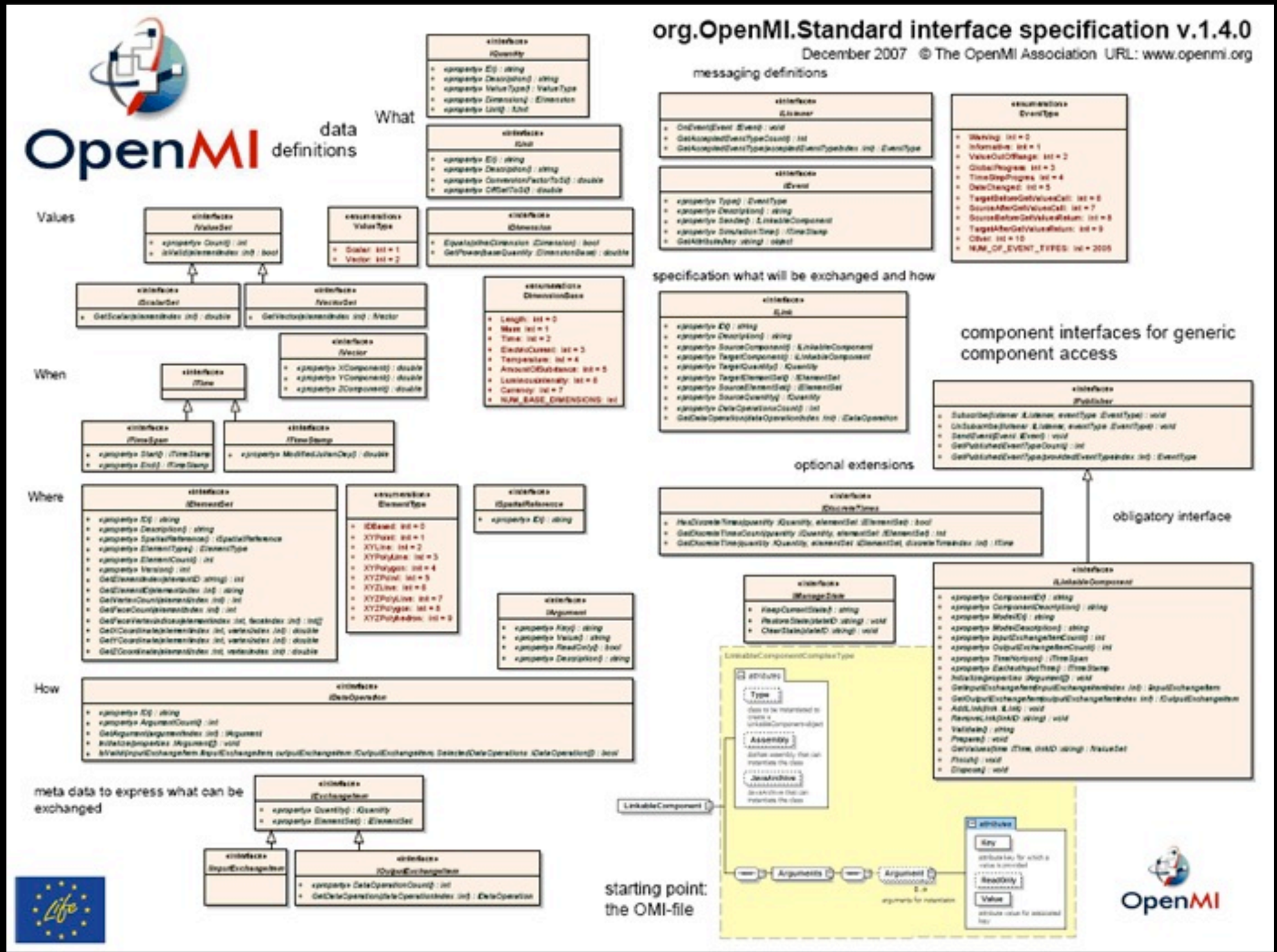
- Written in different languages (conversion is time-consuming and error-prone)
- Code is not well-documented or easy to understand and reuse
- Models have different geometry, dimensionality (1D, 2D or 3D)
- Models may use different types of grids (rectangles, triangles, polygons)
- Each model has its own time loop or "clock"
- Mismatched numerical schemes (explicit vs. implicit).

Problems (software angle - doable)

- Written in different languages (conversion is time-consuming and error-prone)
- Code is not well-documented or easy to understand and reuse
- Models have different geometry, dimensionality (1D, 2D or 3D)
- Models may use different types of grids (rectangles, triangles, polygons)
- Each model has its own time loop or "clock"
- Mismatched numerical schemes (explicit vs. implicit).

Peckham, S. 2010. CSDMS Handbook of Concepts and Protocols: A Guide for Code Contributors. http://csdms.colorado.edu/wiki/Help:Tools_CSDMS_Handbook

Model linking: architectures

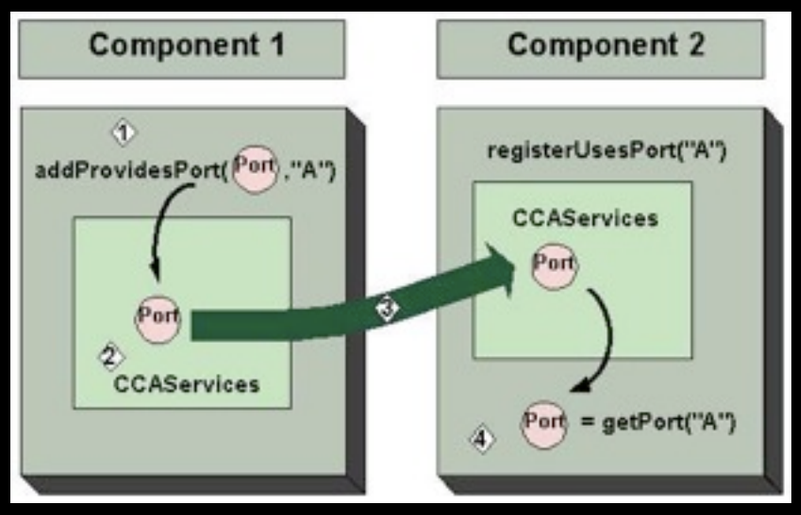


Model linking: architectures

- The Open Modeling Interface and Environment (OpenMI) - a consortium of European universities and private companies develops a standard for model linkage in the water domain.
- Defines an interface that allows time-dependent models to exchange data at runtime.
- Helps to link models from different domains (hydraulics, hydrology, ecology, water quality, economics etc.), environments (atmospheric, freshwater, marine, terrestrial, urban, rural, etc.), different scales, resolutions, platforms, etc.

Model linking: architectures

- Common Component Architecture (CCA) - developed by the DOE and Lawrence Livermore National Lab for high performance computers and complex sophisticated modeling
- CCA supports parallel and distributed computing as well as local high-performance connections between components in a language-independent manner
- Includes:



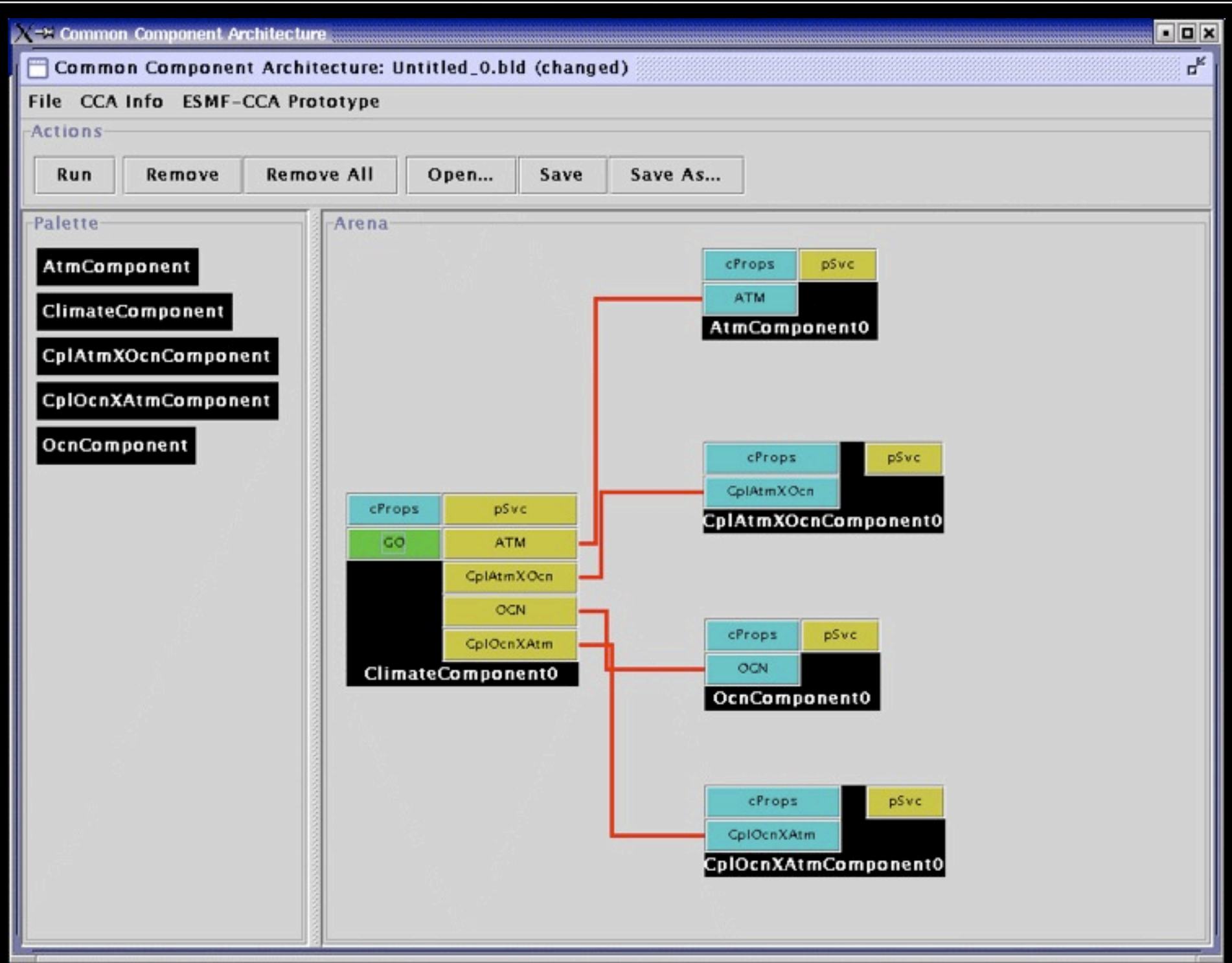
- Babel/SIDL - an object oriented language interoperabilty interface definition language.
- CCA Specification for high performance components.
- Ccaffeine - a CCA framework compliant with the CCA specification.
- Ccaffeine GUI - A Graphical User Interface that works with Ccaffeine.

- CCA is applied in a variety of disciplines, including combustion research, global climate simulation, and computational chemistry.

Bernholdt, et al., 2004. http://www.cca-forum.org/

Model linking: architectures

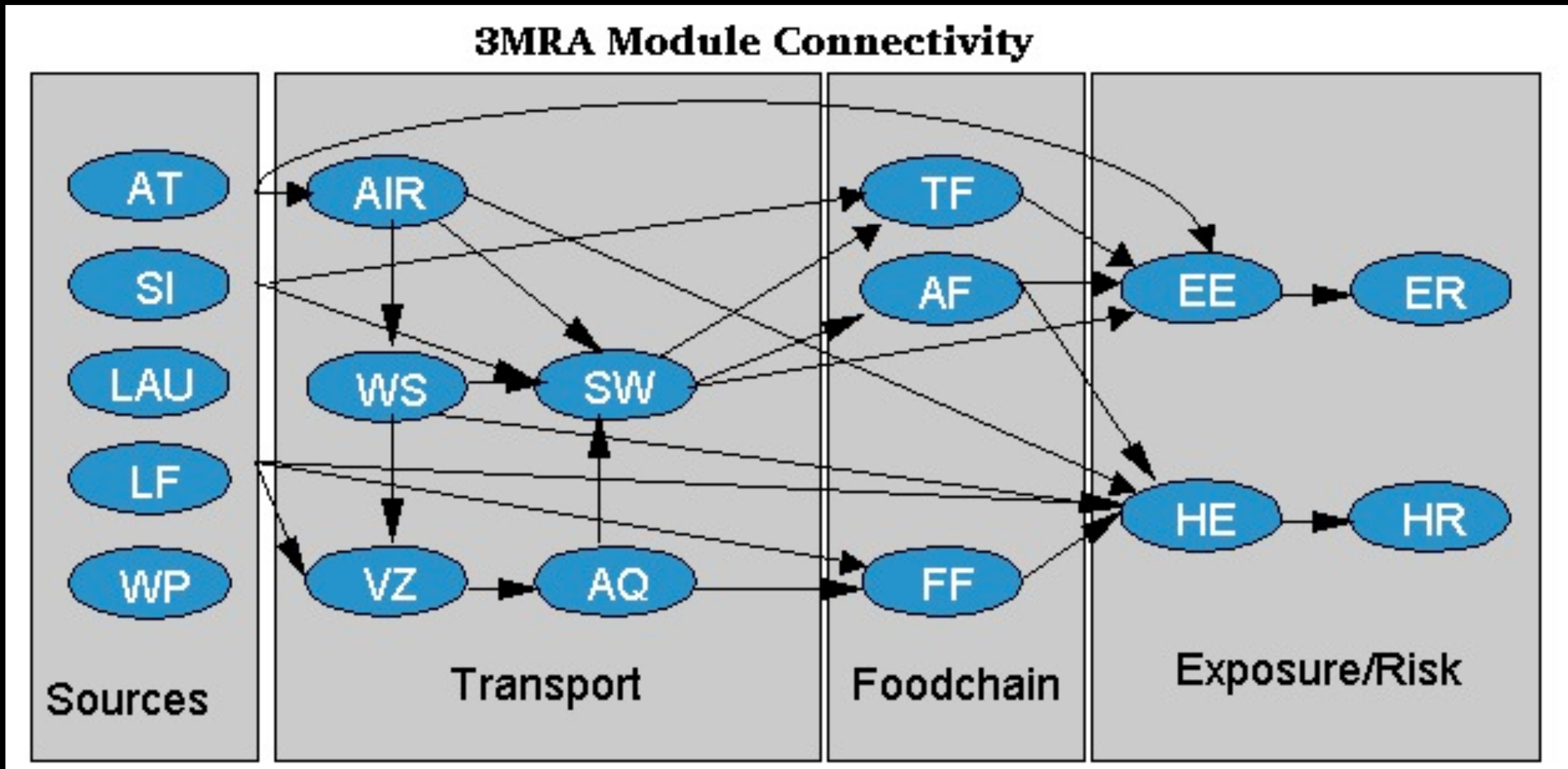
Model linking: architectures



Model linking: architectures

- US EPA - FRAMES (Framework for Risk Analysis in Multi-media Environmental Systems) - system to manage the execution and data flow among science modules
- 3MRA (Multi-media, Multi-pathway, Multi-receptor Risk Analysis) - 17 modules that describe the release, fate and transport, exposure, and risk (human and ecological) associated with contaminants deposited in various land-based waste management units (e.g., landfills, waste piles)
- FRAMES was developed as the framework that would allow these modules to communicate with each other

Model linking: architectures



Problems (modeling angle - iffy)

- Are models software?
- Components built by different teams, at different time, at different places. Built for different goals and purposes.
- Teams use different languages. Need to communicate assumptions. Metadata, metamodels and standards.
- What are the modeling paradigms used? Are they compatible? How do we calibrate integrated models?
- What are the scales? Resolutions? Time, space, structure.
- Propagation of error and uncertainties.
- What are models? Modeling is art or science?

- $E = mc^2$

- E

http://www.abcgallery.com/M/magritte/magritte57.html
Collective Invention. 1934. Oil on canvas. 73.5 x 97.5 cm.
Kunstsammlung Nordrhein-Westfalen, Düsseldorf, Germany.

Integronsters

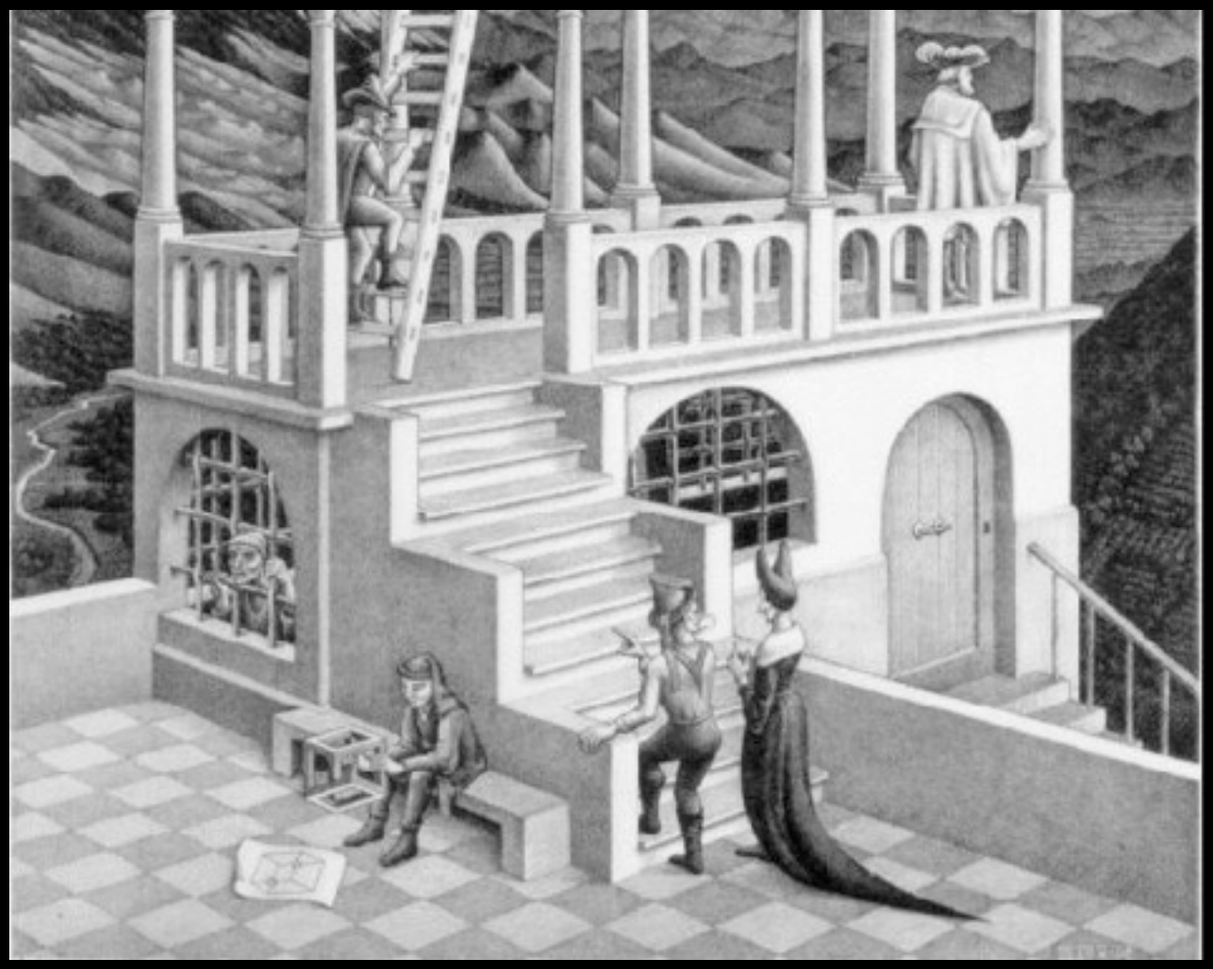
- E

http://www.abcgallery.com/M/magritte/magritte57.html
Collective Invention. 1934. Oil on canvas. 73.5 x 97.5 cm.
Kunstsammlung Nordrhein-Westfalen, Düsseldorf, Germany.

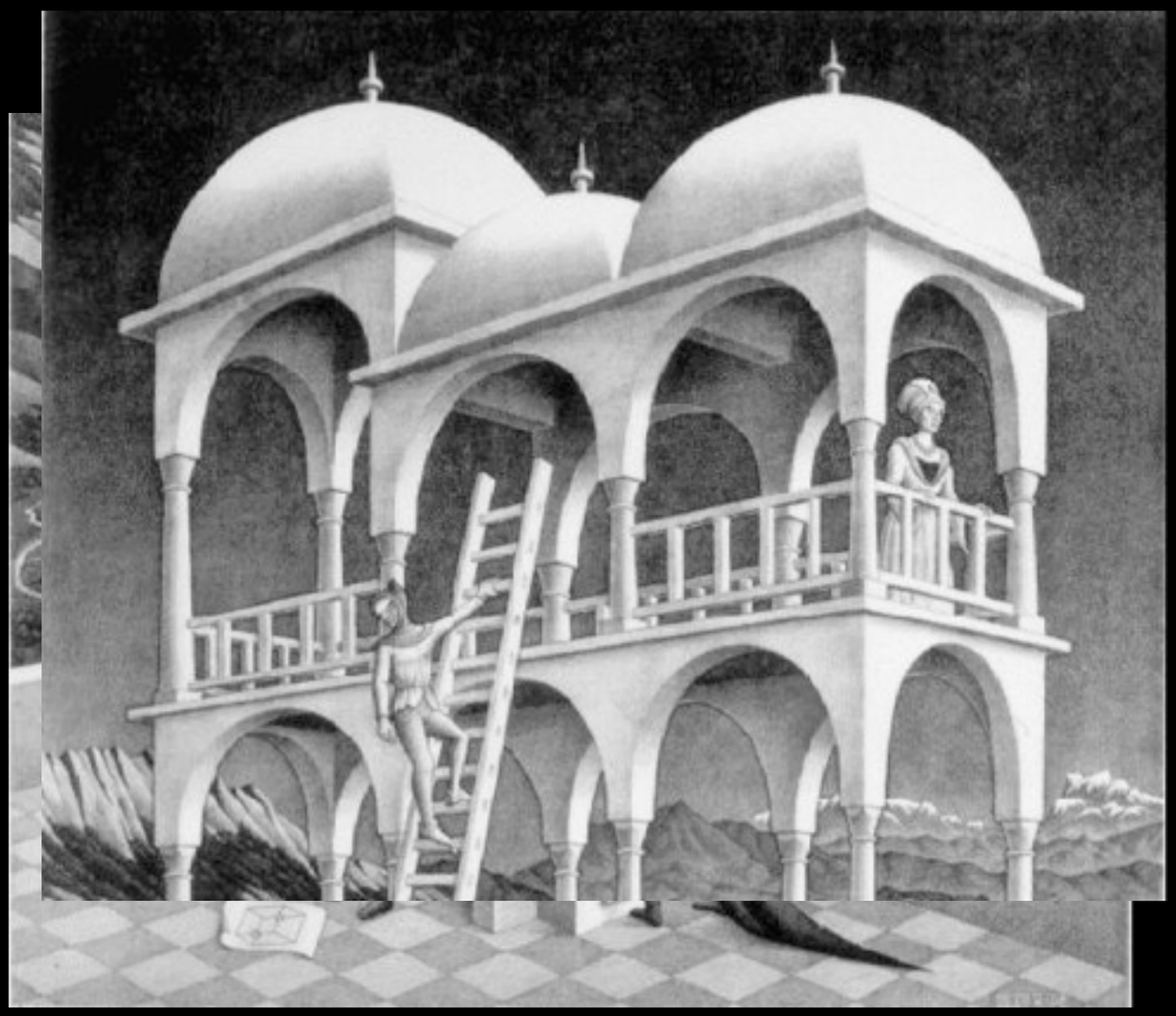
A. Voinov, H.Shugart. 'Integronsters', integral and integrated modeling. (Environmental Modeling and Software: 39)

Integronsters

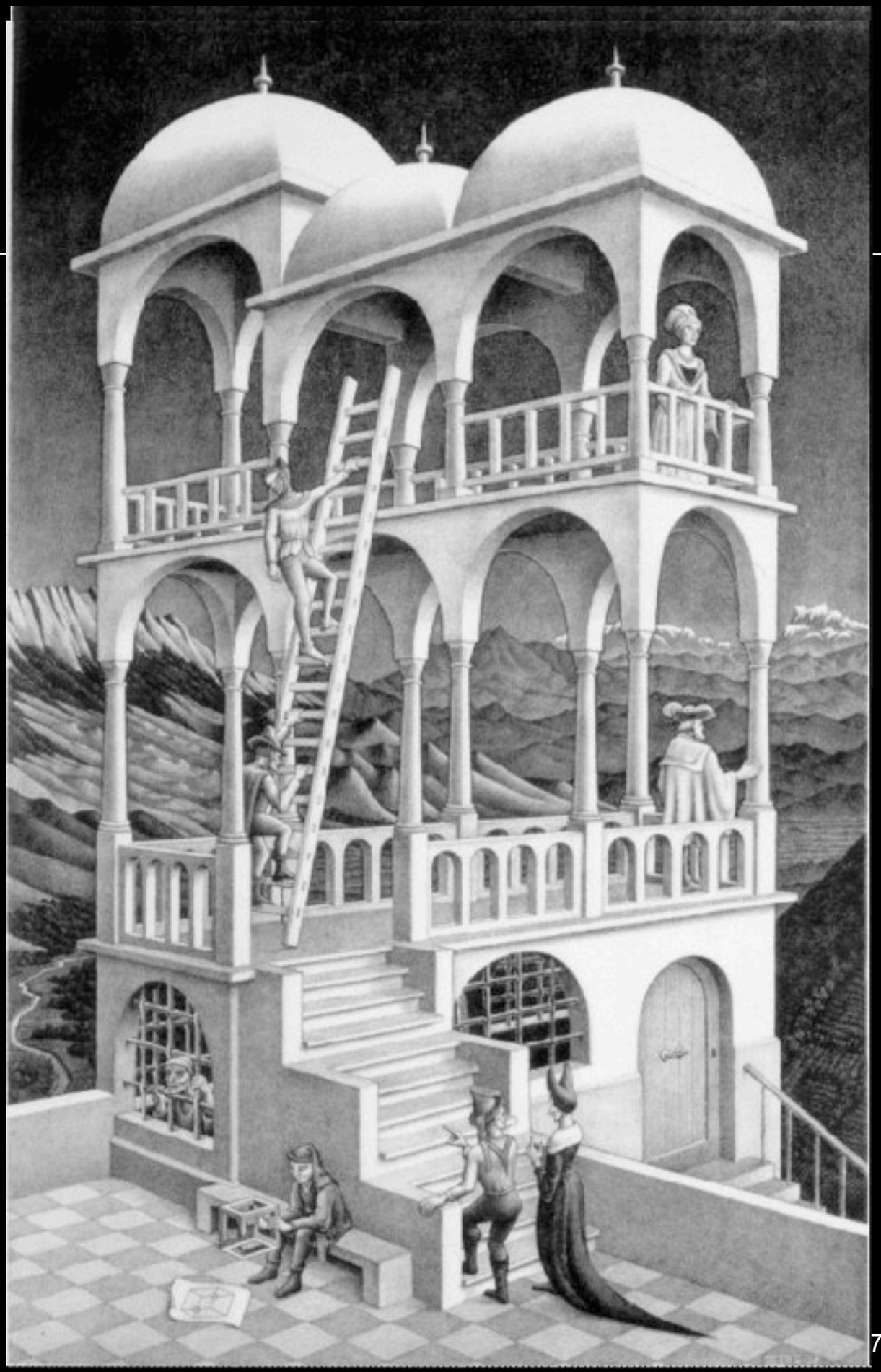
Integronsters: geometry



Integronsters: geometry



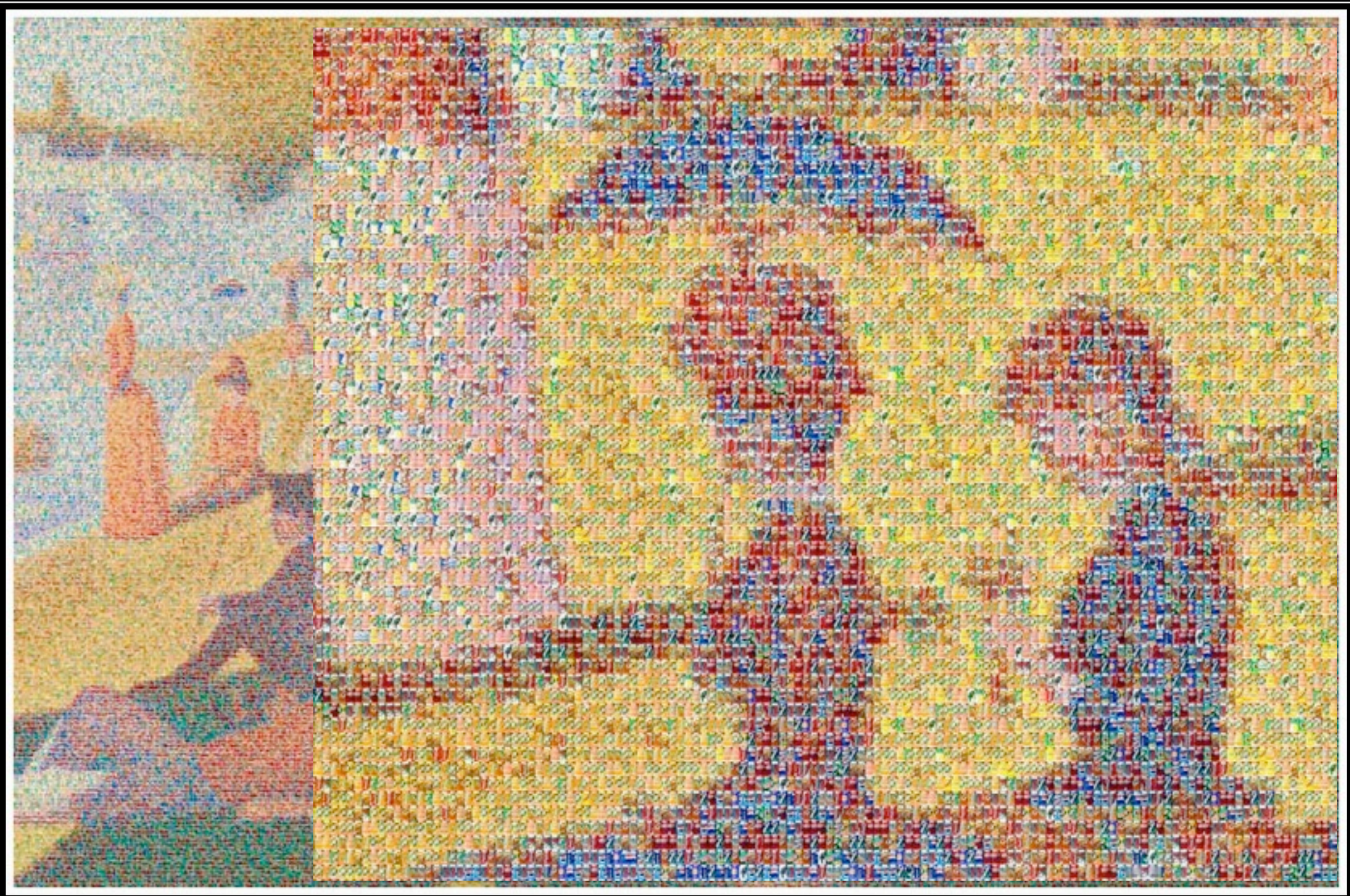
Integronsters: geometry



M.C. Escher
Belvedere 1958 Lithograph
http://www.mcescher.net/target4.html

Resolution

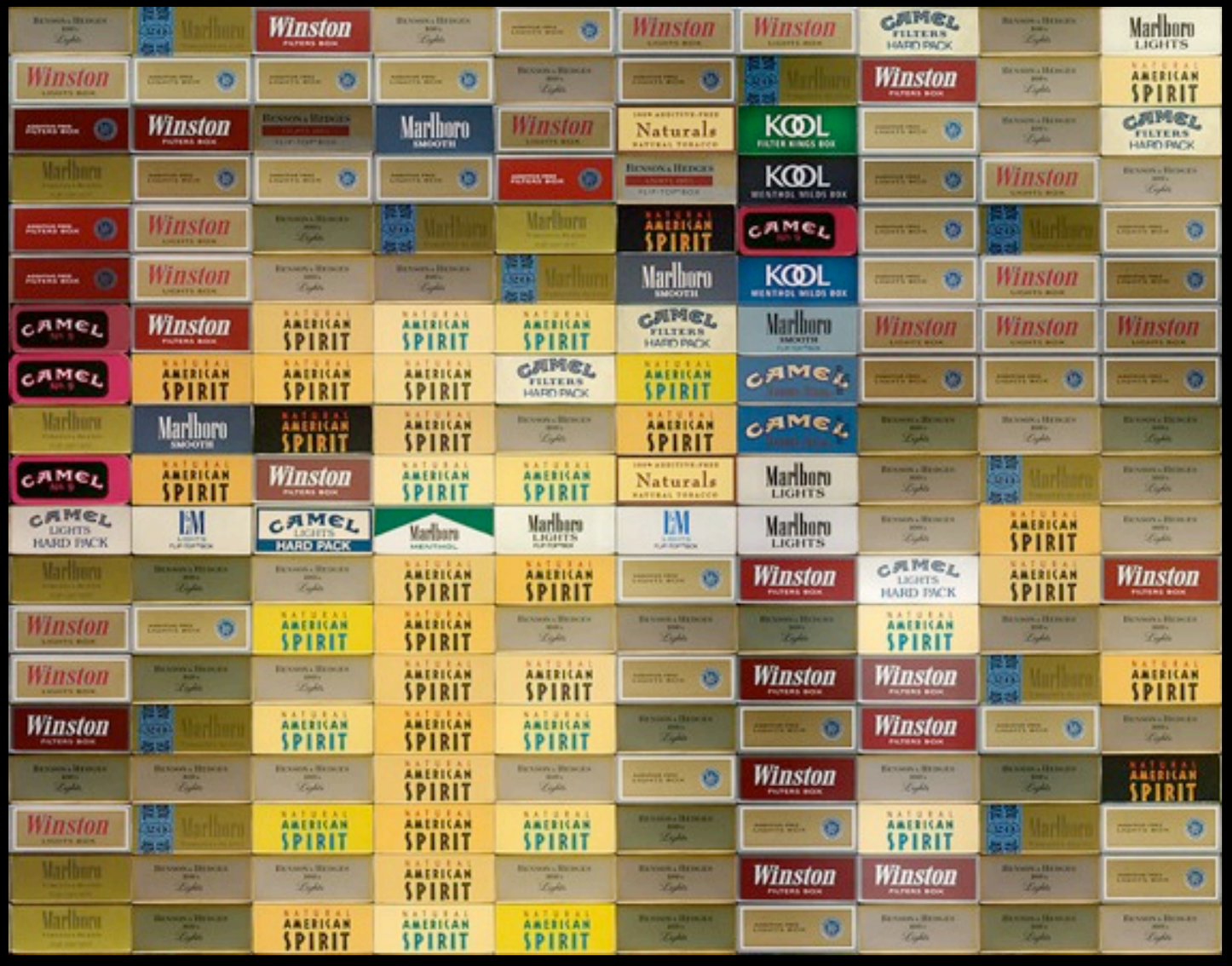
Resolution



Resolution

Chris Jordan, Seattle, 2008. Running the Numbers - An American Self-Portrait
Cans Seurat, 2007, 60x92 - Depicts 106,000 aluminum cans, the number used in the US every thirty seconds - http://www.chrisjordan.com/current_set2.php

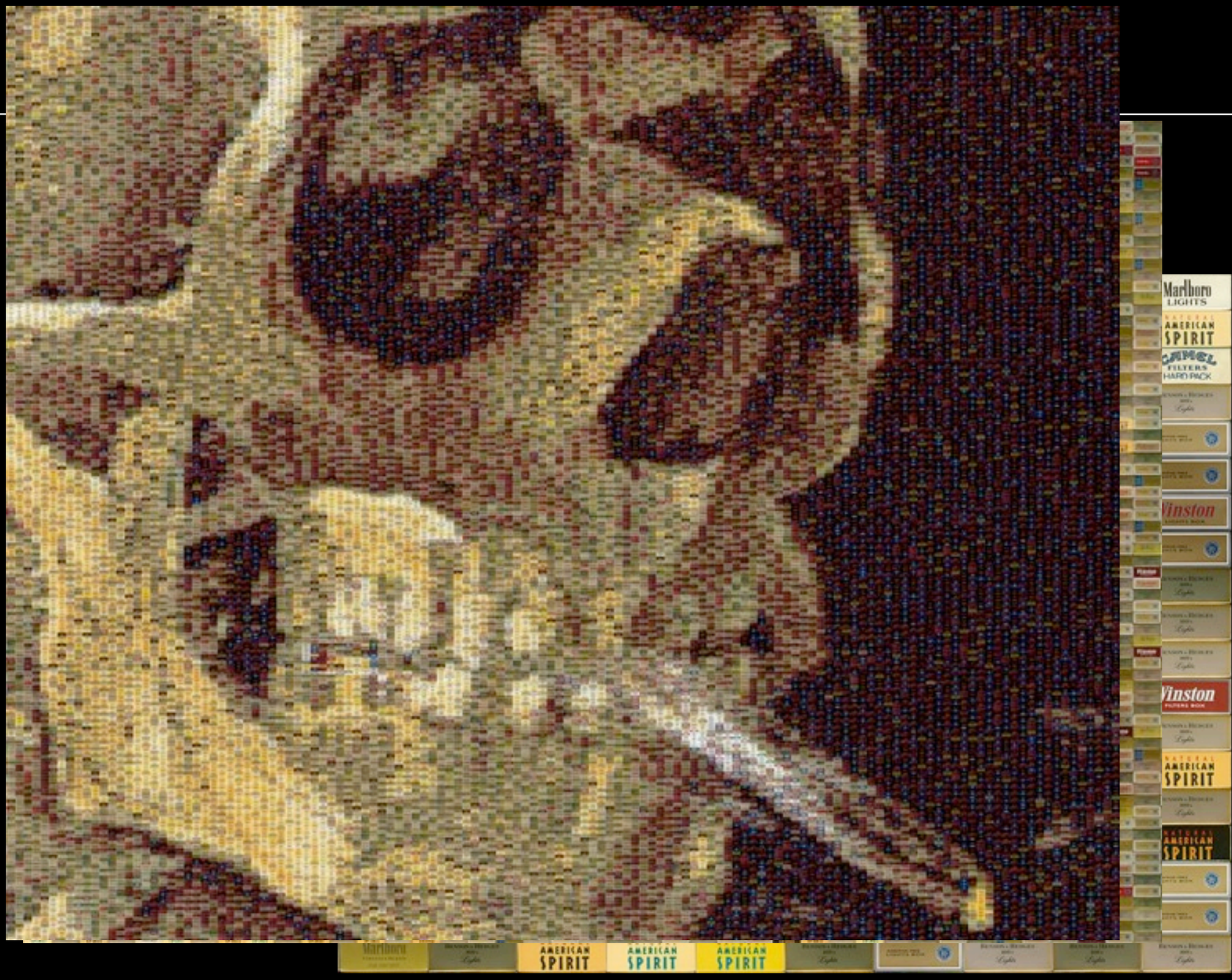
Resolution


Winston
Marlboro
Marlboro LIGHTS
CAMEL FILTERS HARD PACK
NATURAL AMERICAN SPIRIT
Naturals
KOOL
CAMEL
CAMEL LIGHTS HARD PACK
E&M

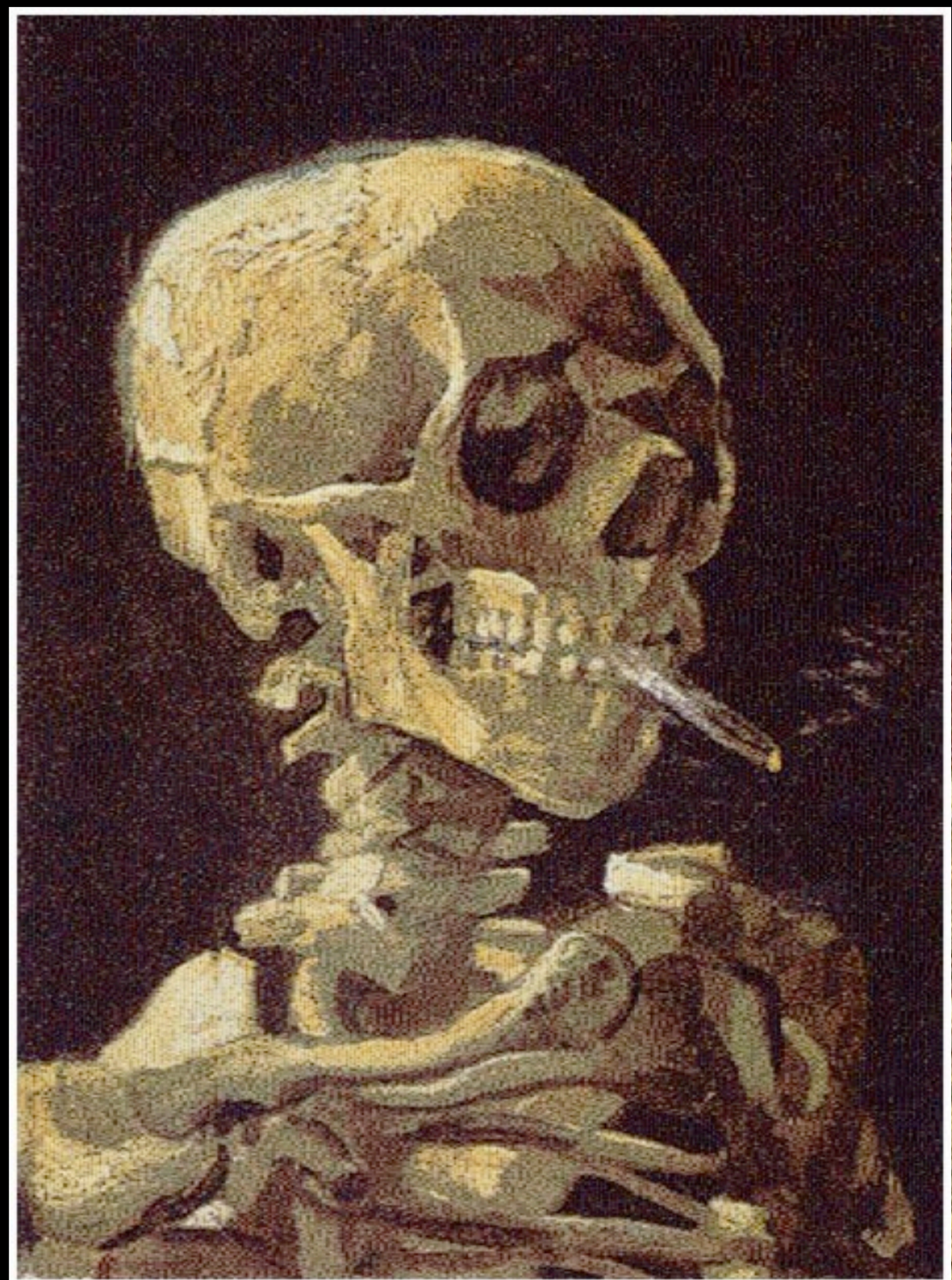
Resolution

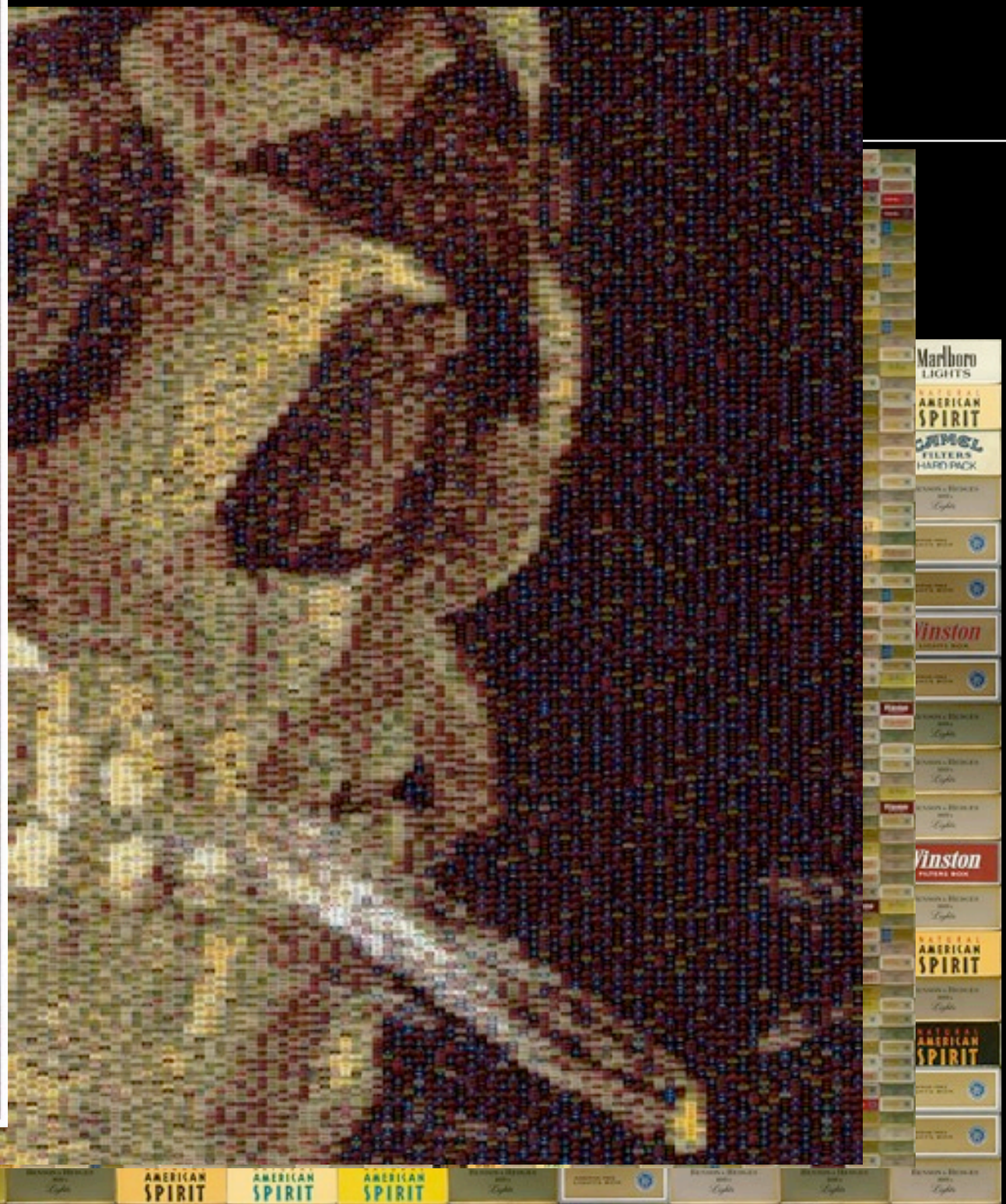
Marlboro
LIGHTS
AMERICAN
SPIRIT
CAMEL
FILTERS
HARD PACK
Winston
AMERICAN
SPIRIT
AMERICAN
SPIRIT
AMERICAN
SPIRIT
AMERICAN
SPIRIT

Resolution


Marlboro
LIGHTS
AMERICAN
SPIRIT
CAMEL
FILTERS
HARD PACK
Winston
AMERICAN
SPIRIT
AMERICAN
SPIRIT
AMERICAN
SPIRIT

Resolution





Chris Jordan, Seattle, 2008
Running the Numbers - An American Self-Portrait
Skull With Cigarette, 2007 [based on a painting by Van Gogh] - 98X72"
Depicts 200,000 packs of cigarettes, equal to the number of Americans who die from cigarette smoking every six months.
- http://www.chrisjordan.com/current_set2.php

Integronsters: bull in a china shop

Community modeling approach

- How do we communicate modules?
- Open up the modeling process
- A community modeling system is an open-source suite of modeling components coupled in a framework
- Model emerges through the collective efforts of a community of individuals that develop, code, debug, test, document, run, and apply the modeling system
- Include both developers and users, and distribute among different institutions and organizations.

Voinov, A.A., C. DeLuca, R. R. Hood, S. Peckham, C. R. Sherwood, J. P. M. Syvitski, 2010. A Community Approach to Earth Systems Modeling. EOS, Transactions, American Geophysical Union, V.91, N.13, p. 117–124.

Community modeling approach

- First generation:
  - EPA's Models-3 System,
  - National Center for Atmospheric Research (NCAR) Community Climate Model (CCM)
  - Pennsylvania State/NCAR Mesoscale Model (MM5)
- Proof of concept: freely available, portable, well-documented models are enthusiastically received by the broader community as research tools

Community modeling approach

- Next generation:
  - Community Climate System Model (CCSM), the successor to CCM. Was part of IPCC assessments;
  - Weather Research and Forecast (WRF) Model, the successor to MM5;
  - Community Surface Dynamics Modeling System (CSDMS; http://csdms.colorado.edu - NSF);
  - Community Modeling and Analysis System (CMAS; http://www.cmascenter.org/ - EPA);
  - Chesapeake Community Model Program (CCMP; http://ccmp.chesapeake.org - NOAA);
  - Community Sediment-Transport Model System (CSTMS; http://www.cstms.org - NOPP)

Community modeling

Community modeling

- Bottom-up development:

  Community for Integrated Environmental Modeling (CIEM)

  http://groups.google.com/group/commiem?hl=en

Community modeling

- Bottom-up development:

  Community for Integrated Environmental Modeling (CIEM)

  http://groups.google.com/group/commiem?hl=en
- Dying off with no funding and champions

Community modeling

- Bottom-up development:

  Community for Integrated Environmental Modeling (CIEM)

  http://groups.google.com/group/commiem?hl=en
- Dying off with no funding and champions
- The EarthCube (http://www.nsf.gov/geo/earthcube/):

Community modeling

- Bottom-up development:

  Community for Integrated Environmental Modeling (CIEM)

  http://groups.google.com/group/commiem?hl=en
- Dying off with no funding and champions
- The EarthCube (http://www.nsf.gov/geo/earthcube/):
  - “Transformative concepts and approaches to create integrated data management infrastructures across the Geosciences”

Community modeling

- Bottom-up development:

  Community for Integrated Environmental Modeling (CIEM)

  http://groups.google.com/group/commiem?hl=en
- Dying off with no funding and champions
- The EarthCube (http://www.nsf.gov/geo/earthcube/):
  - “Transformative concepts and approaches to create integrated data management infrastructures across the Geosciences”
- Modeling: is it art or science?

Community modeling

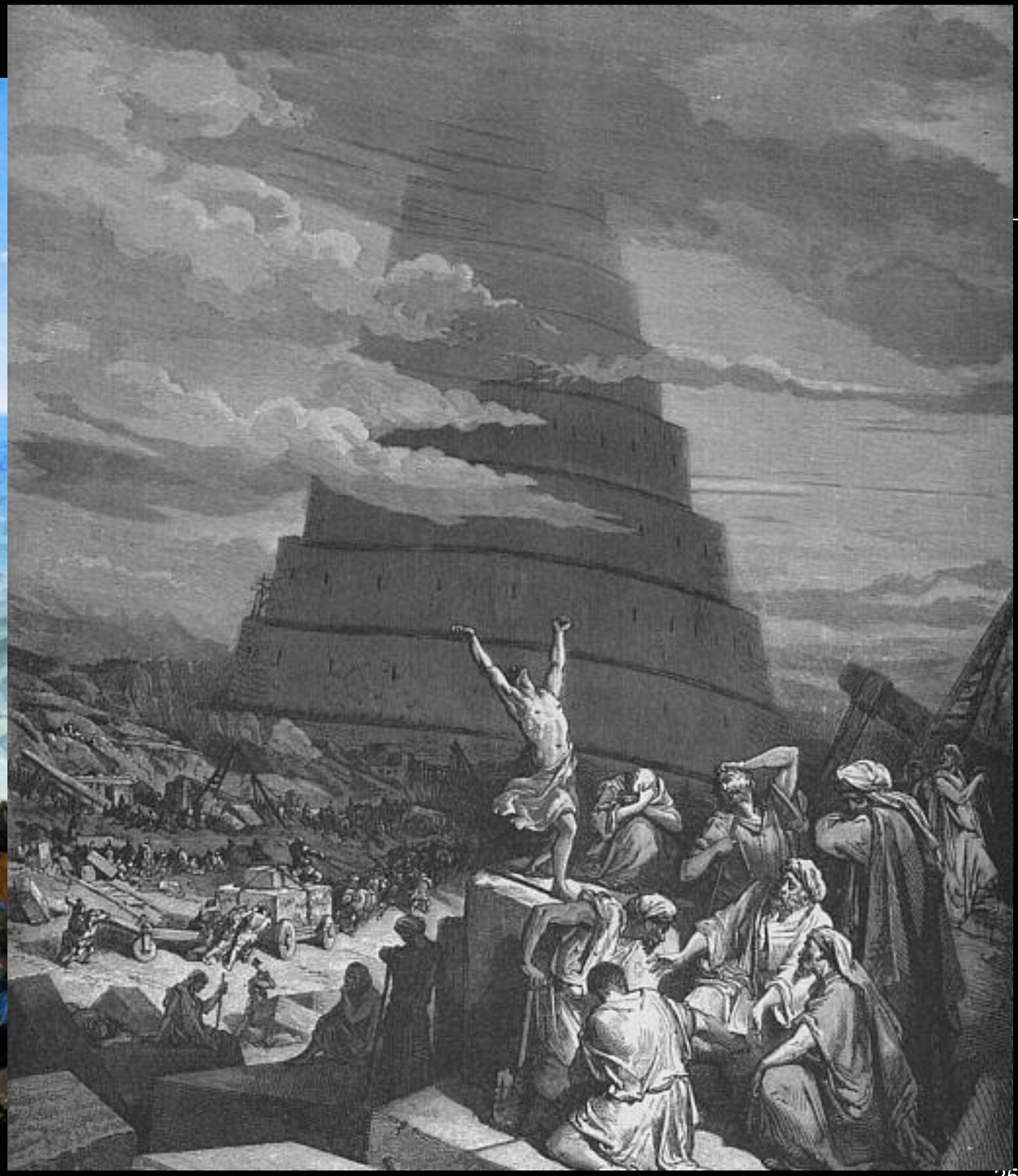
- Bottom-up development:

  Community for Integrated Environmental Modeling (CIEM)

  http://groups.google.com/group/commiem?hl=en
- Dying off with no funding and champions
- The EarthCube (http://www.nsf.gov/geo/earthcube/):
  - “Transformative concepts and approaches to create integrated data management infrastructures across the Geosciences”

- Modeling: is it art or science?
- "Collaboration: When a collection of brilliant minds, hearts and talents come together ... expect a masterpiece..."

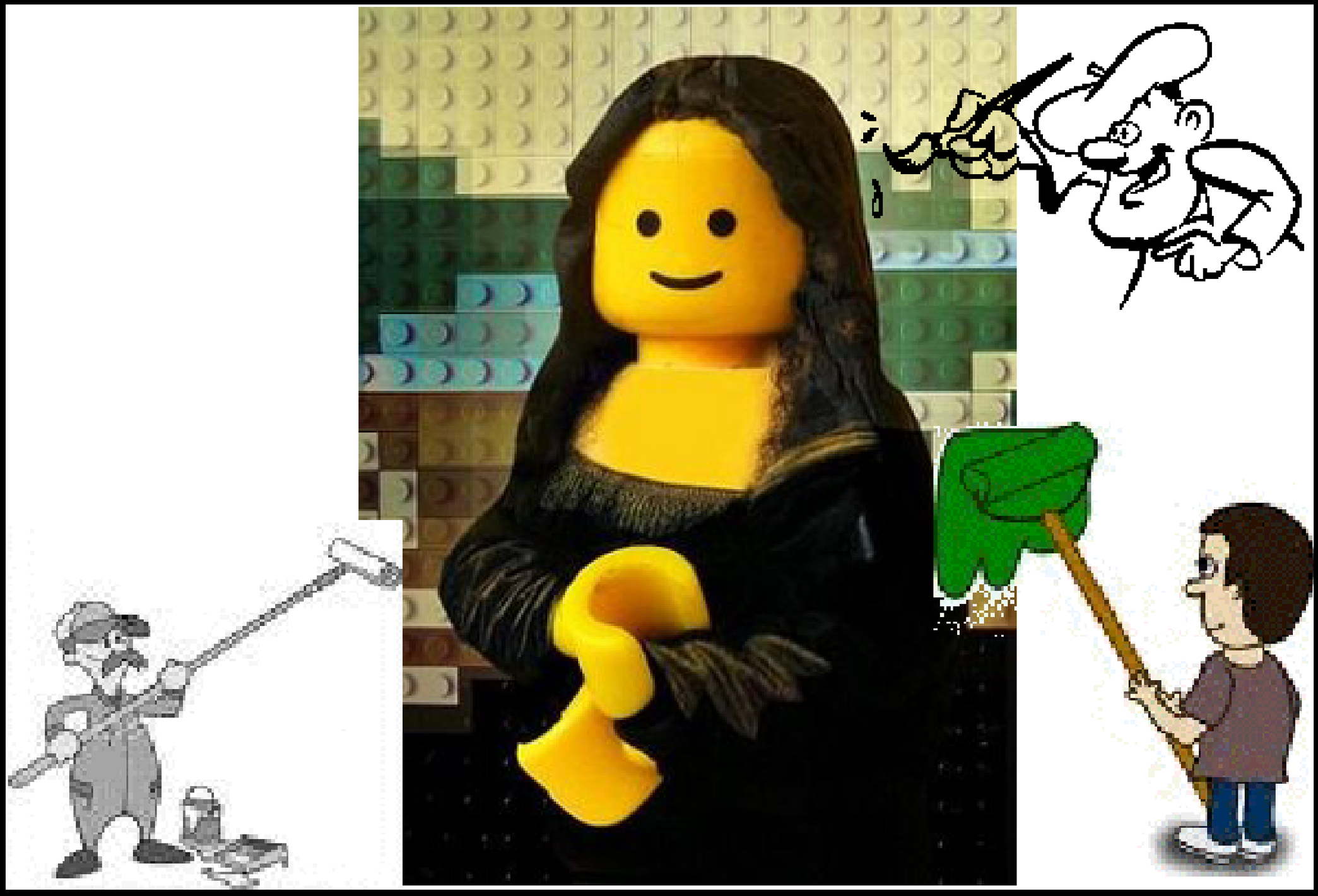
  but...



ALZT OP
MOST HET
THOECHSTE WAS
DOEN NIET VALLEN
BABELON
GENESIS

Team work

Team work



Community modeling recommendations

- Code should be open source and meet standards or protocols as a requirement for receiving government funds;
- Communities should have a say in disbursement of funding. Community programs are transparent and can help to decide on funding priorities and focal areas;
- Require that models, code and documentation be accessible during development;
- Provide stable funding of software architects and engineers on par with the technical staff support in labs
- Support repositories of models and software and enforce standards among themselves.

The complexity curse

- With integration, models are becoming even more complex
- “A complex model may be more realistic yet at the same time more uncertain”*
- Complex models are hard to test
- Complex models are hard to communicate
- Complex models are hard to trust
- Complex models are hard to calibrate
- In environmental modeling calibration is a must.

* Oreskes, N., 2003. "The role of quantitative models in science," in Models in Ecosystem Science, Ed: C. D. Canham, J. J. Cole, and W. K. Lauenroth (Princeton: Princeton University Press), pp. 13-31.

Voinov, A., and C. Cerco. 2010. Model integration and the role of data. Environmental Modelling & Software 25, no. 8: 965-969.

Models and data

- Jetten et al. (1999): comparing performance of 14 catchment models concluded that uncalibrated use of models is not advisable;

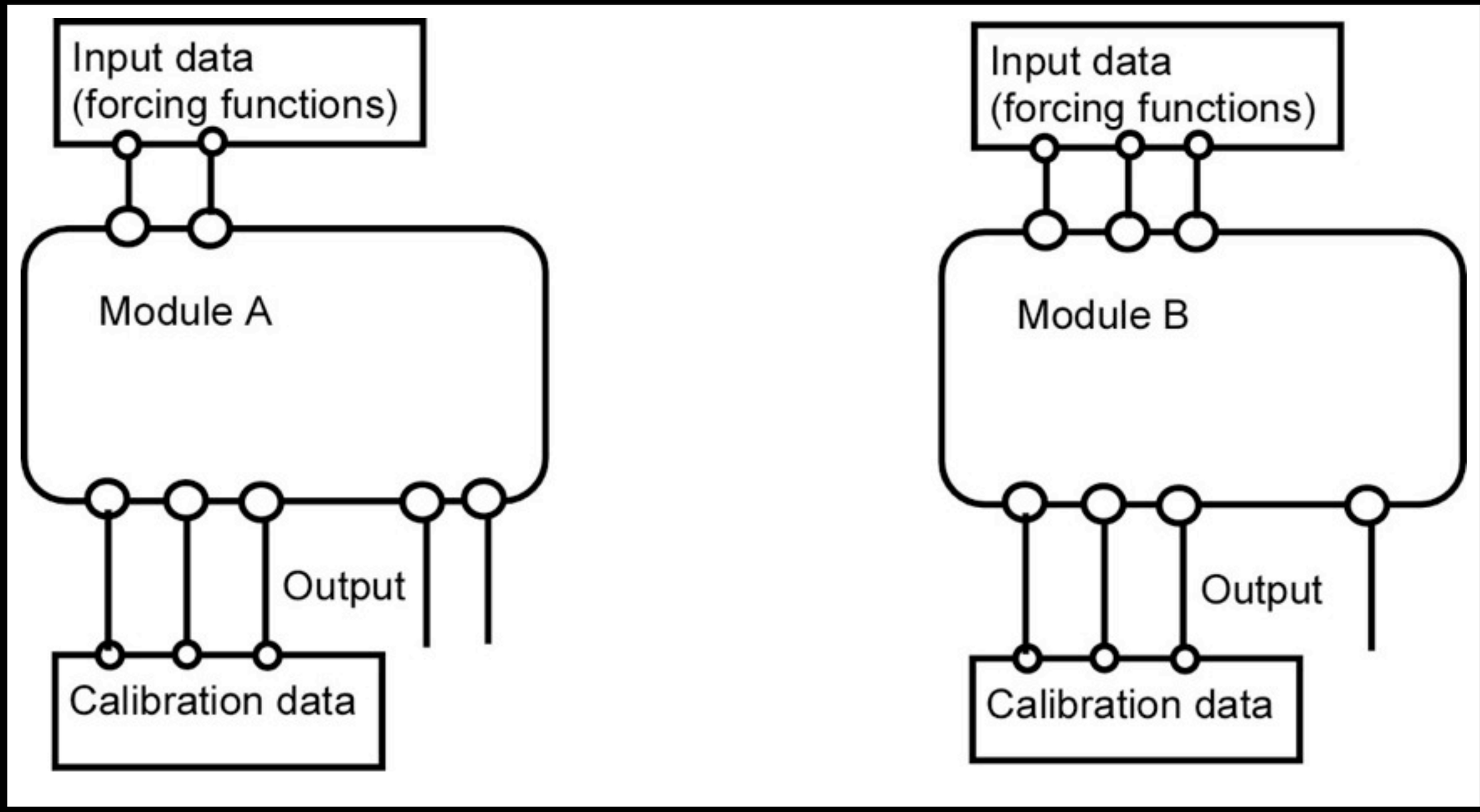
Models and data

- Jetten et al. (1999): comparing performance of 14 catchment models concluded that uncalibrated use of models is not advisable;
- Bormann et al. (2007): when calculating scenarios that were out of the calibration domain, different models produced quite different results;

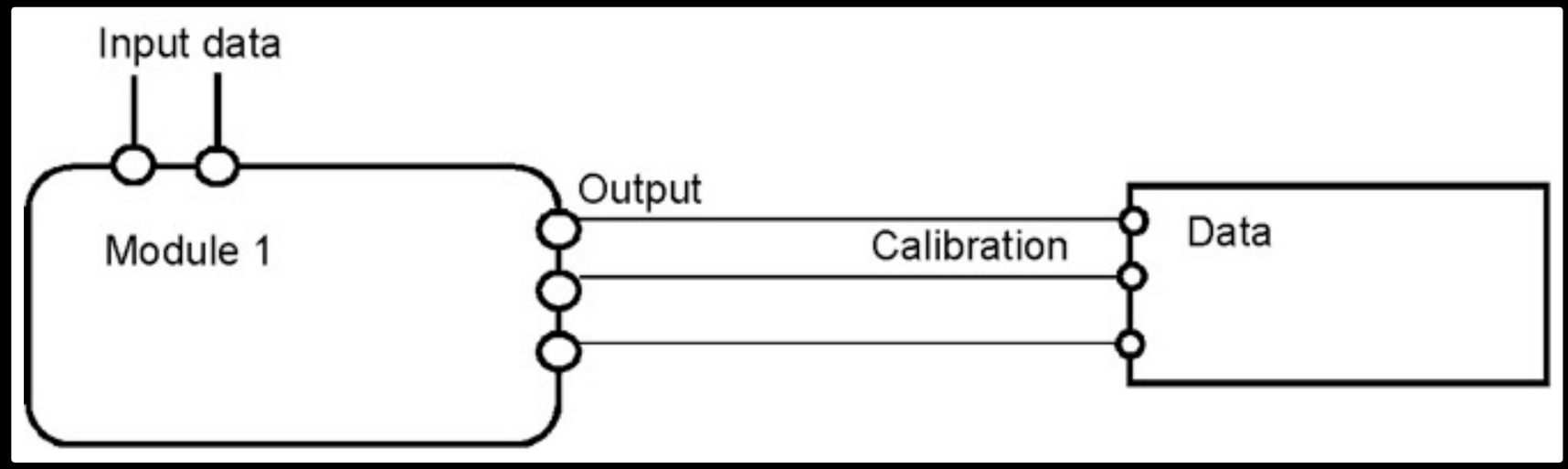
Models and data

- Jetten et al. (1999): comparing performance of 14 catchment models concluded that uncalibrated use of models is not advisable;
- Bormann et al. (2007): when calculating scenarios that were out of the calibration domain, different models produced quite different results;
- Silberstein (2006): more data are needed and models without data are not science

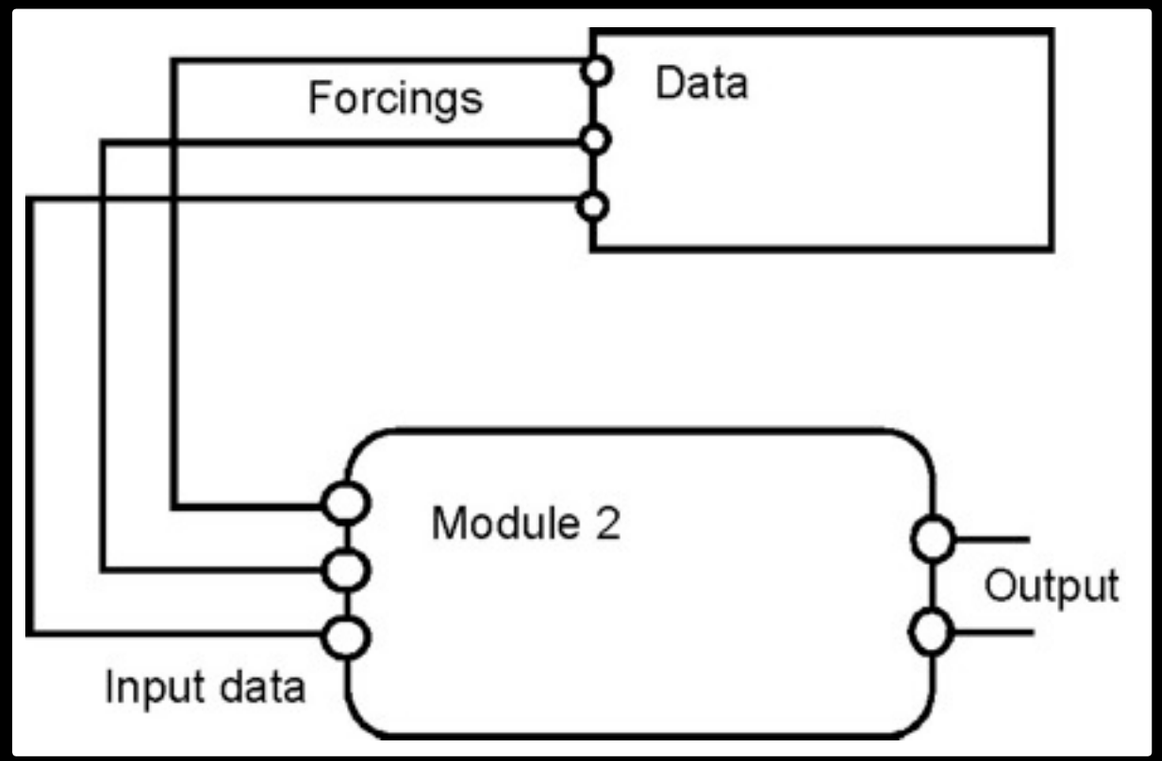
Model linking



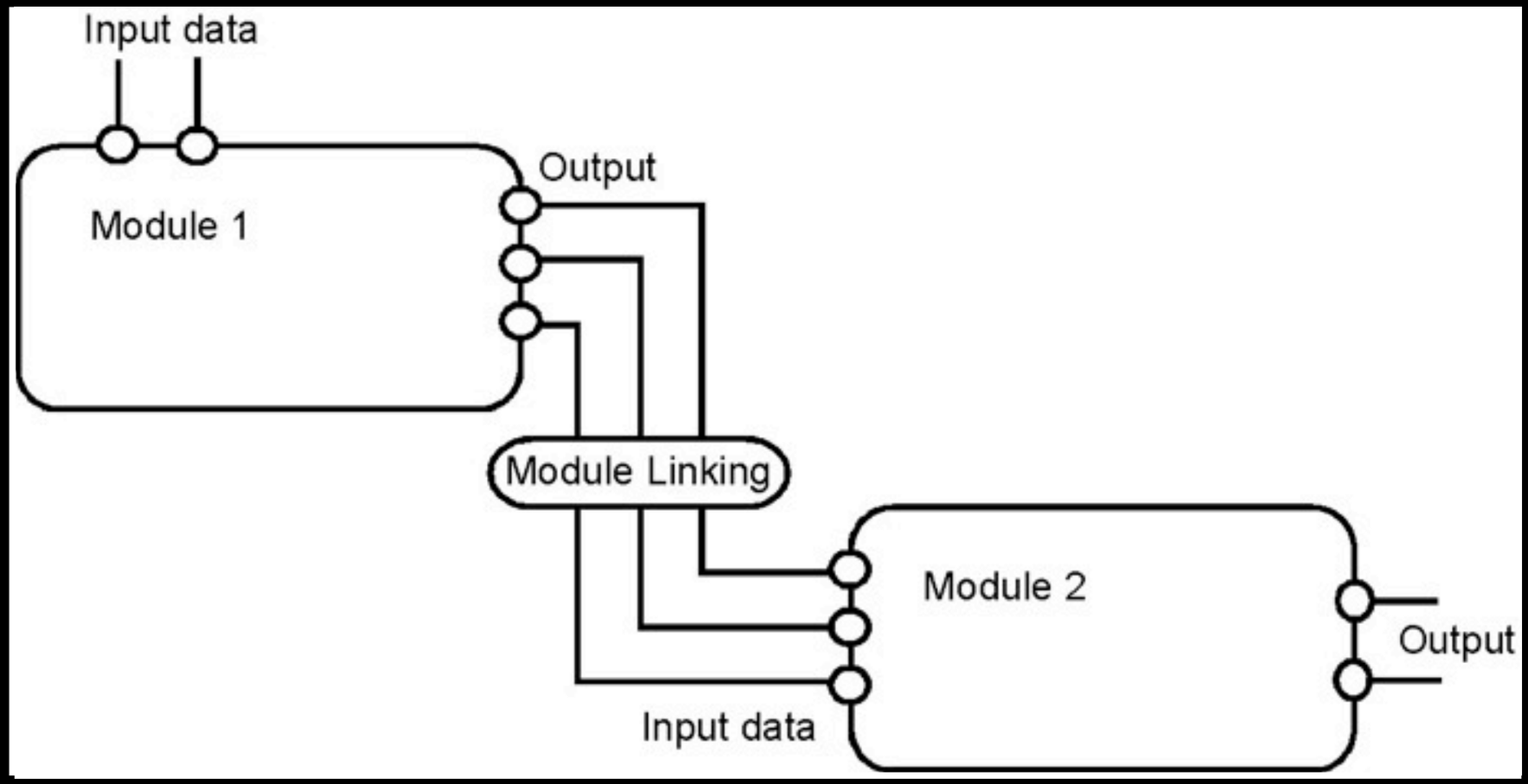
Models and data

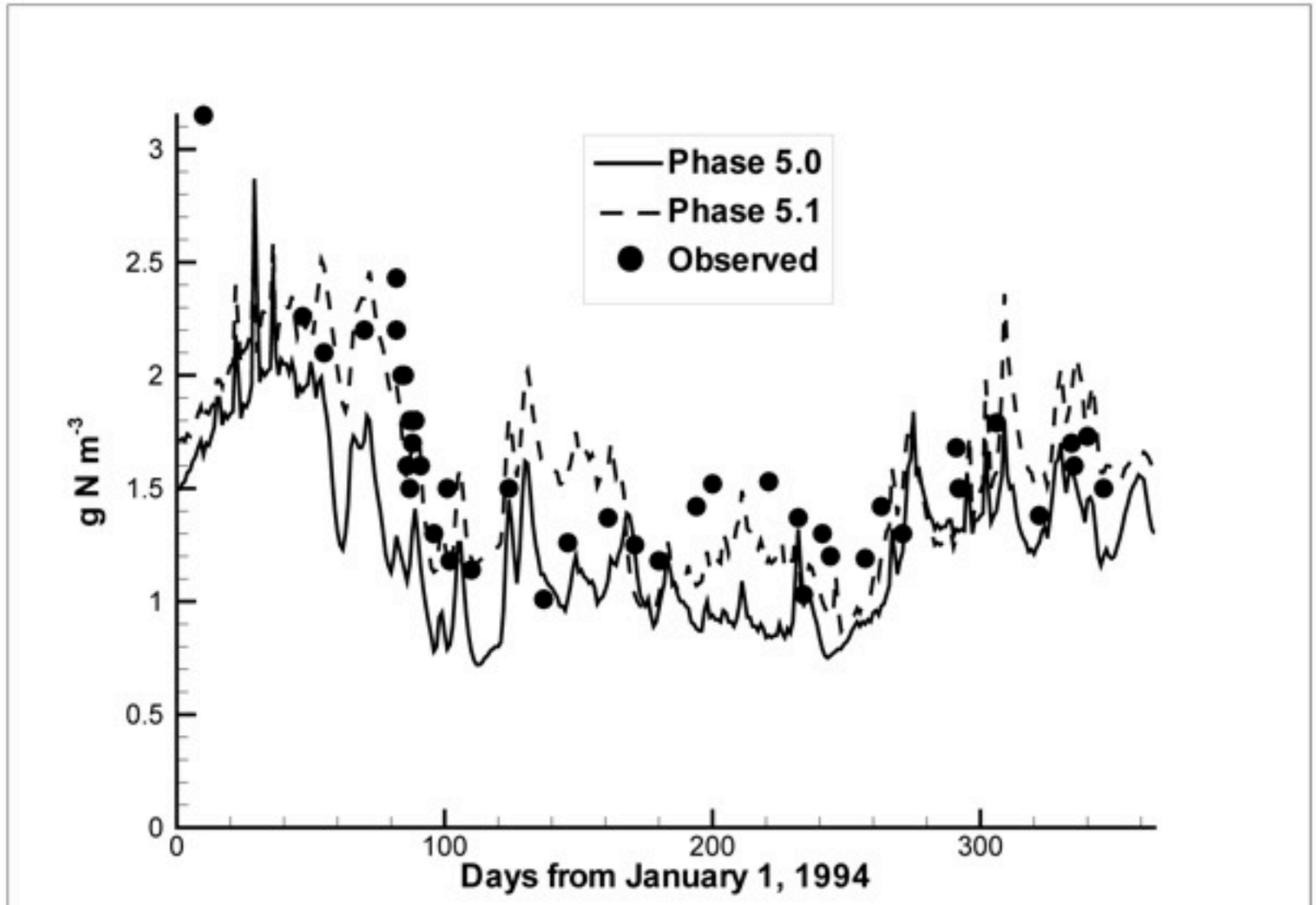


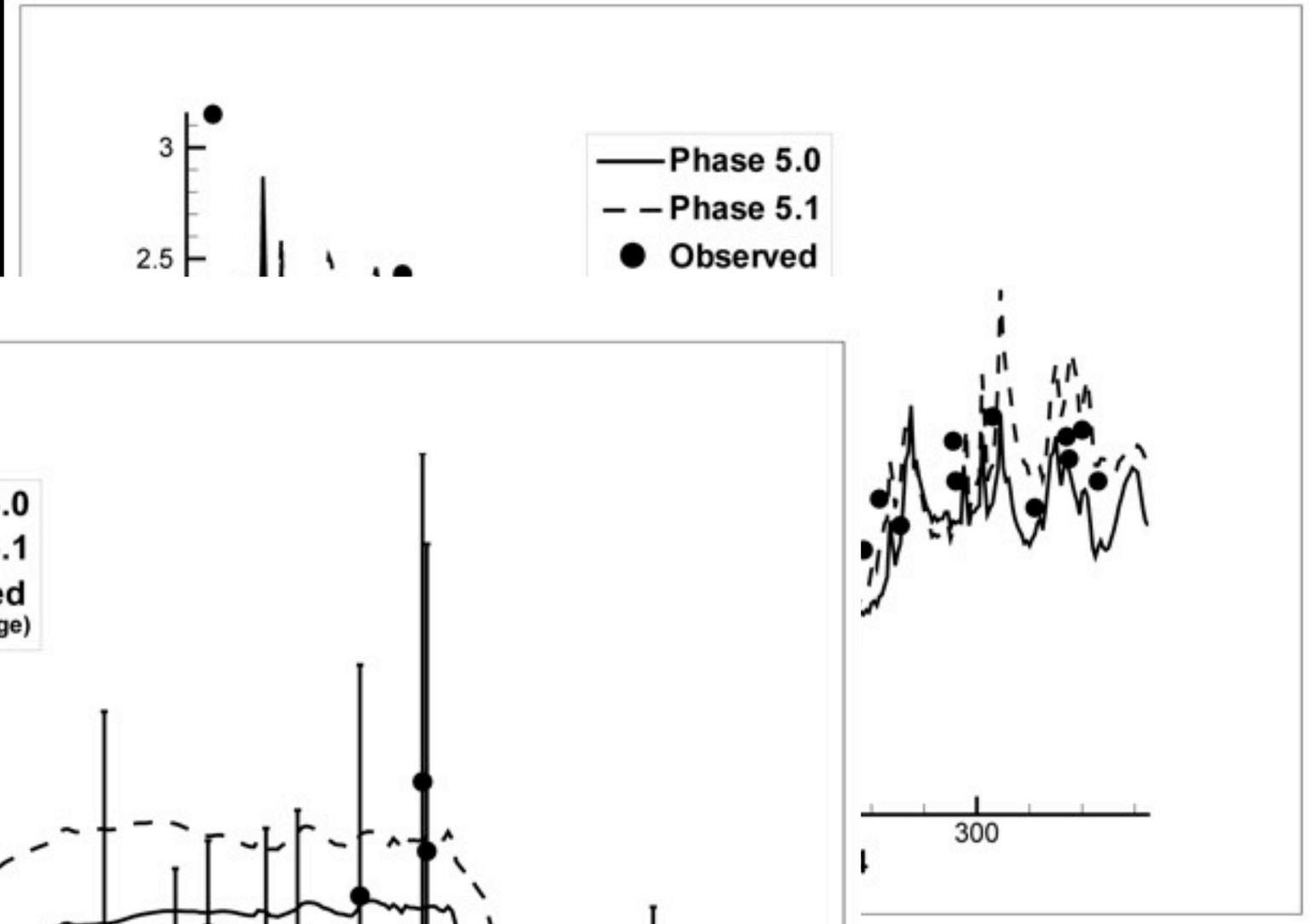
Models and data

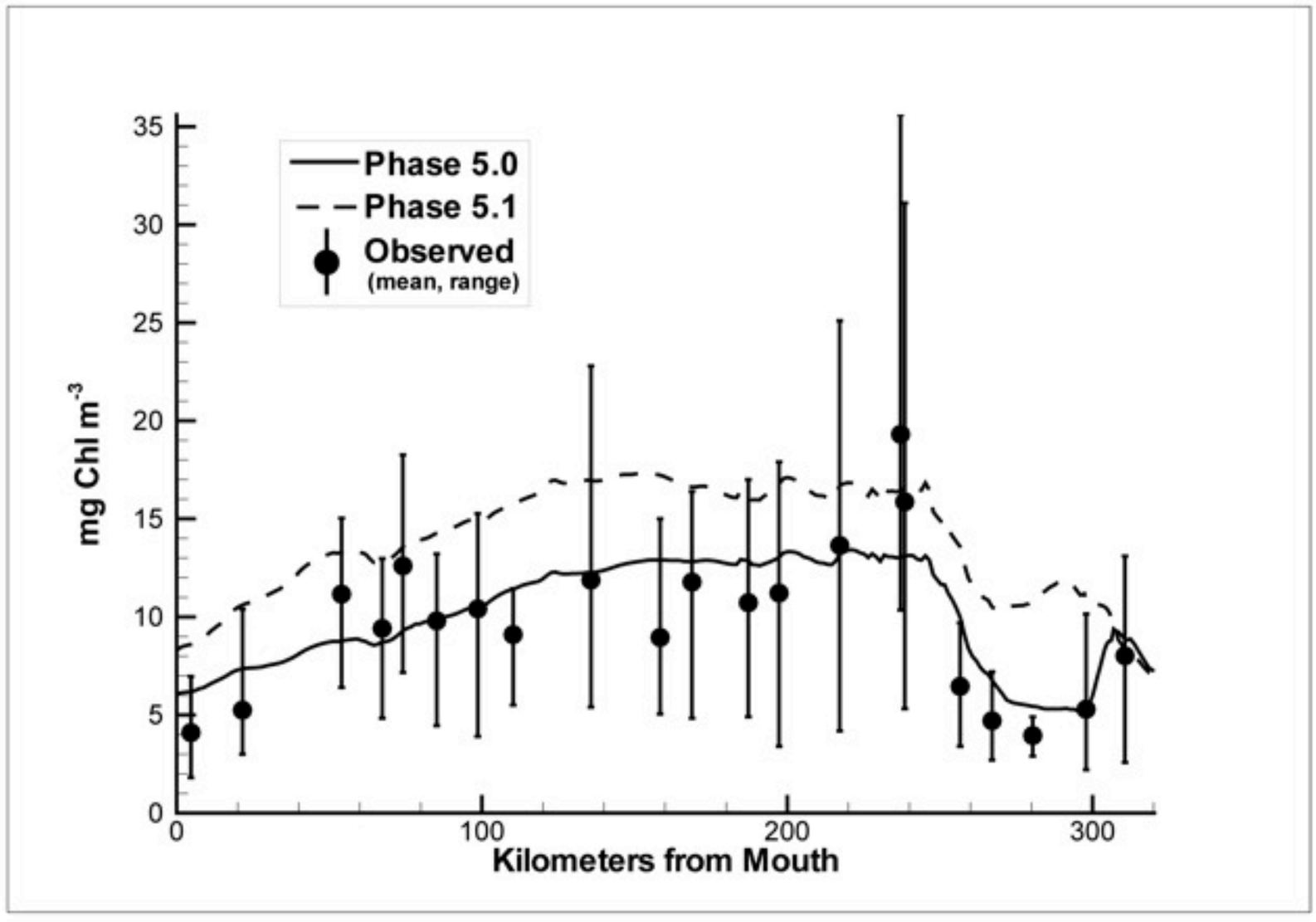


Models and data

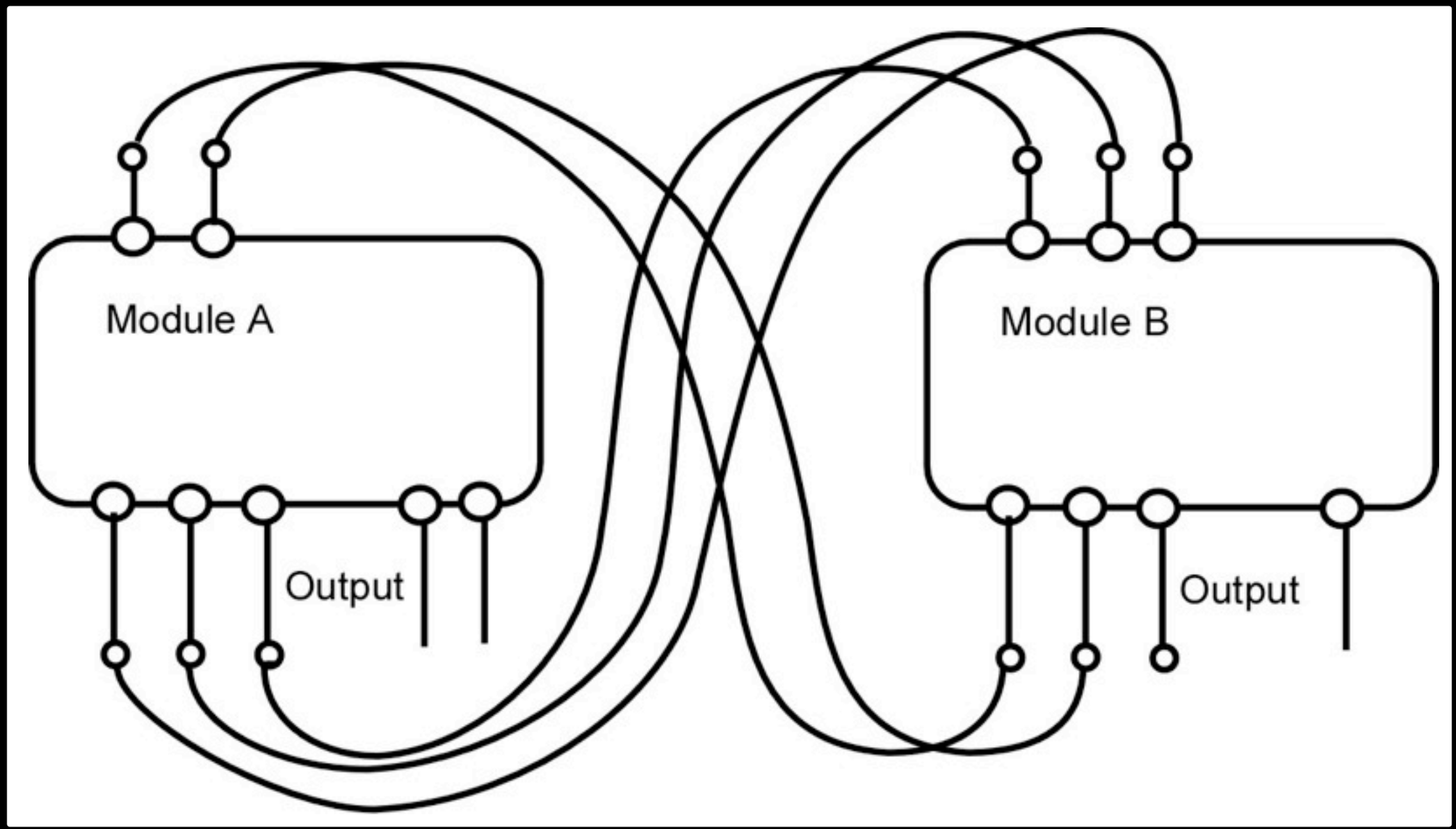



Phase 5.0
Phase 5.1
Observed
g N m-3
3
2.5
2
1.5
1
0.5
0
0
100
200
300
Days from January 1, 1994

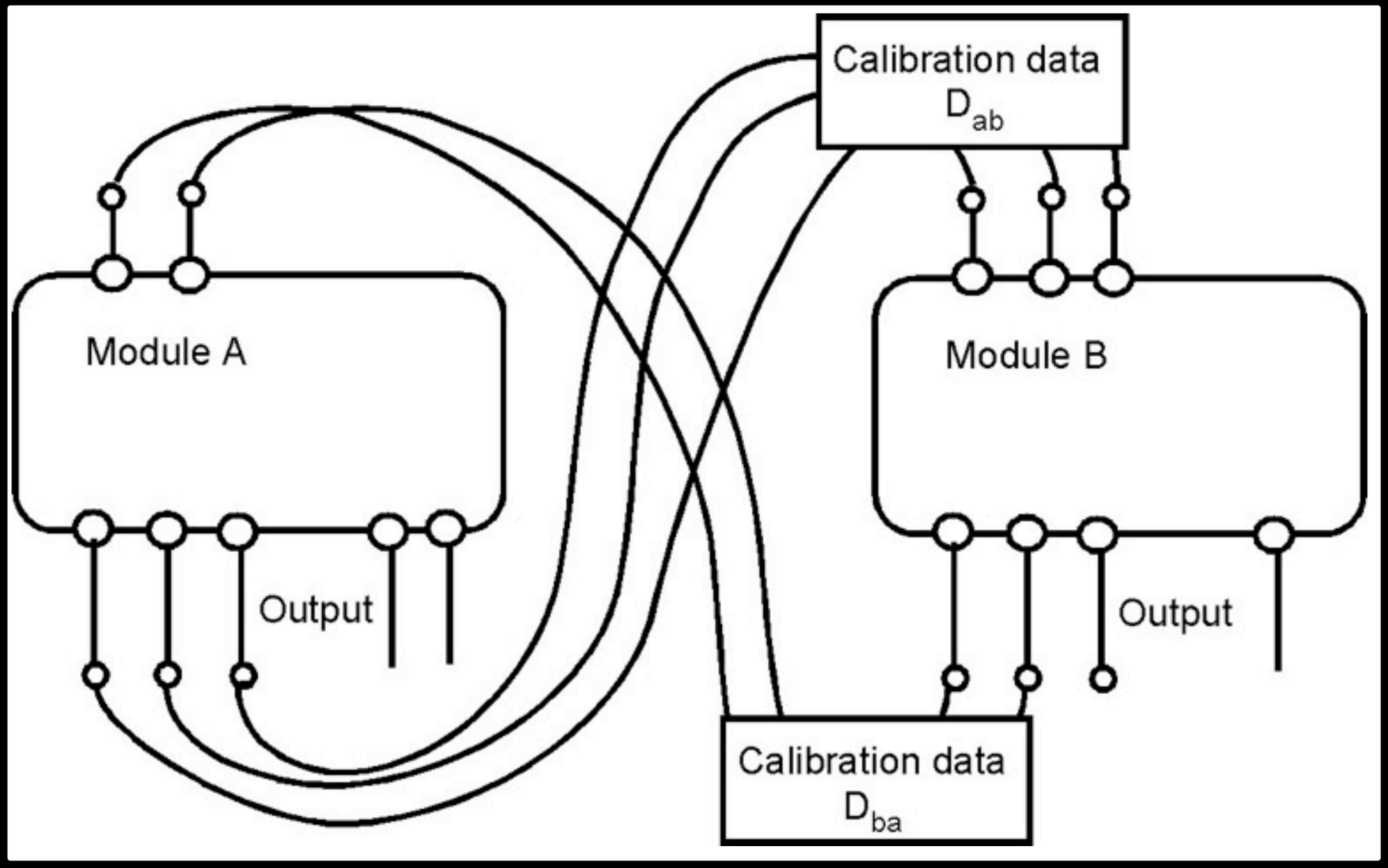

3
2.5
Phase 5.0
Phase 5.1
Observed
300


35
30
25
20
15
10
5
0
mg Chl m-3
Phase 5.0
Phase 5.1
Observed
(mean, range)
0
100
200
300
Kilometers from Mouth

Model linking



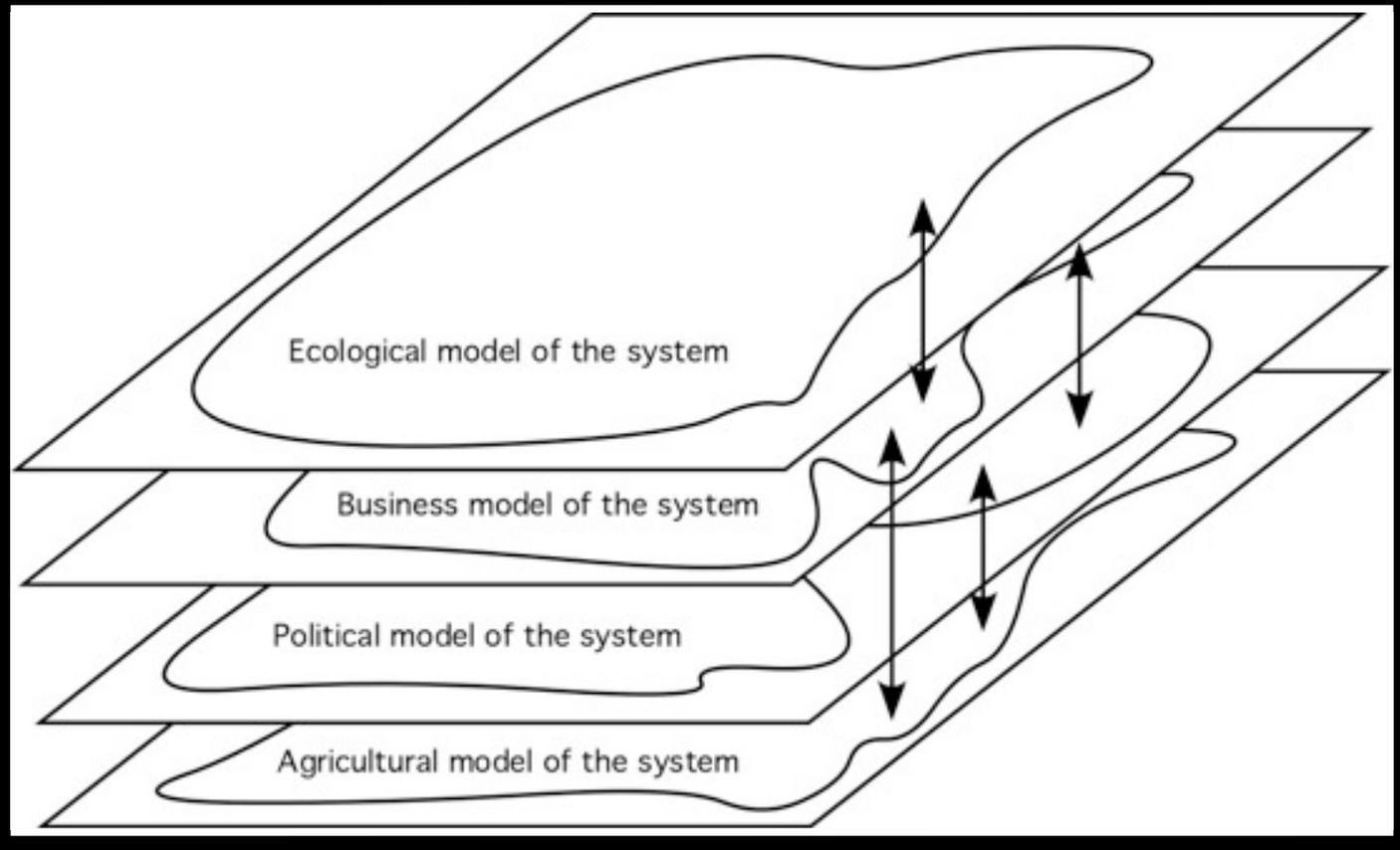
Integrating with data



Voinov, A., and C. Cerco. 2010. Model integration and the role of data. Environmental Modelling & Software 25, no. 8: 965-969.

Integral modeling

- Built by the same team
- Uses the same modeling paradigm
- More interested in the overall system dynamics rather than in the detailed analysis of what can happen
- Has a disciplinary bias
- Integration of knowledge

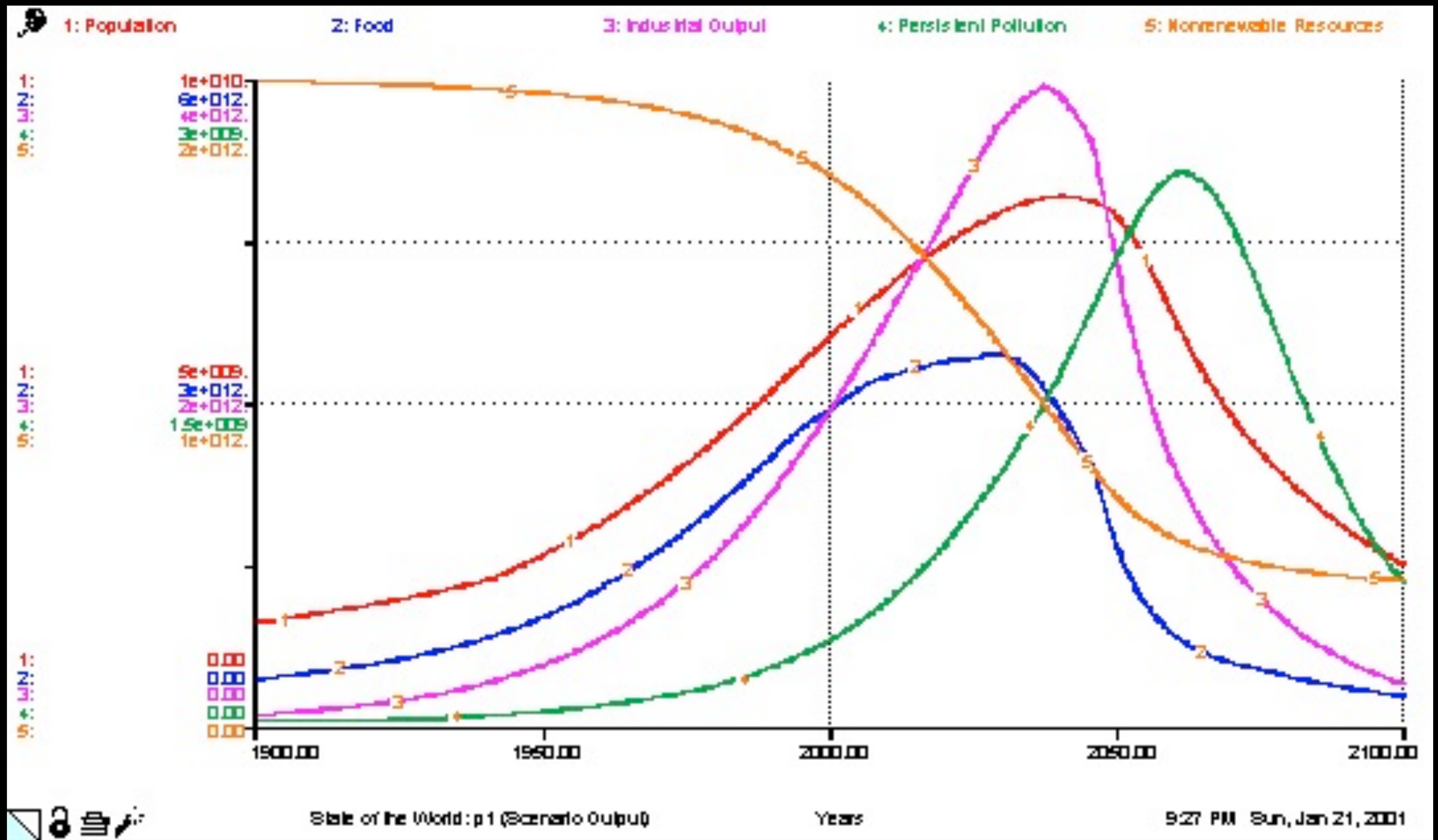


Laniak, G., et al. Integrated Environmental Modeling: A Vision and Roadmap for the Future. (Environmental Modeling and Software: 39)

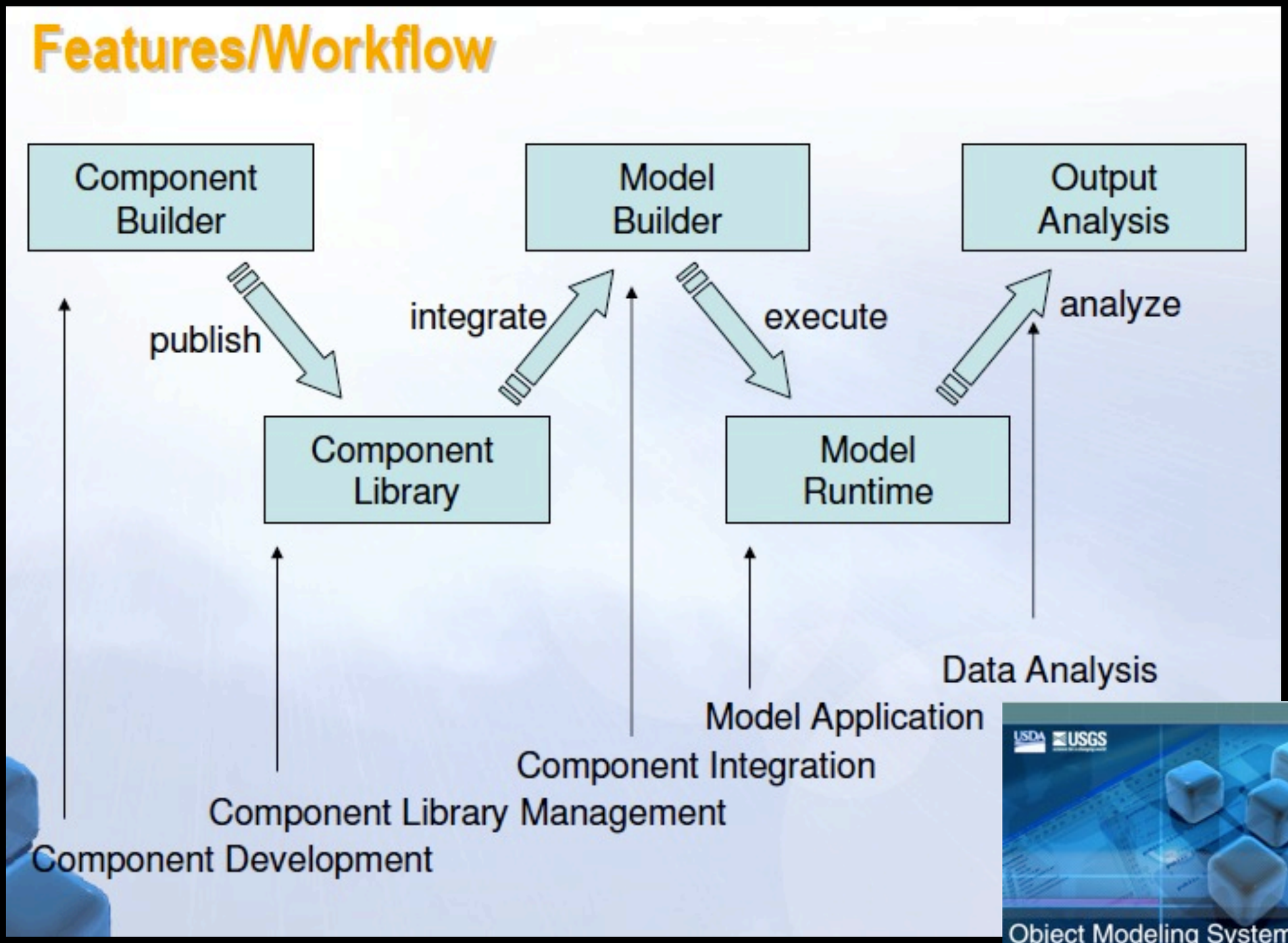
Integral models

- Club of Rome models - World3 (http://www.whole-systems.org/world3.html)
  - food system (agriculture and food production)
  - industrial system
  - population system
  - non-renewable resources system
  - pollution system.

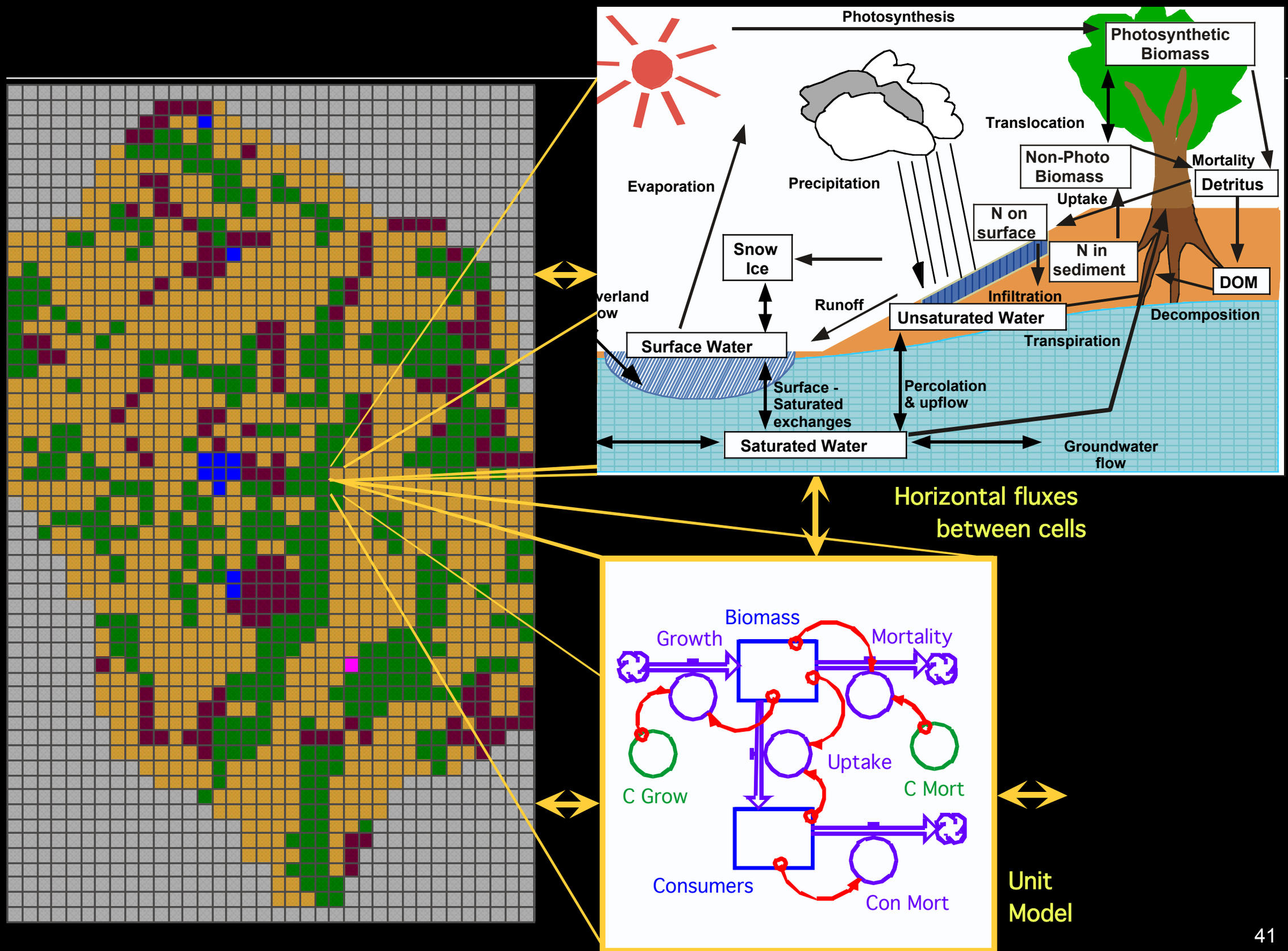
Integral models



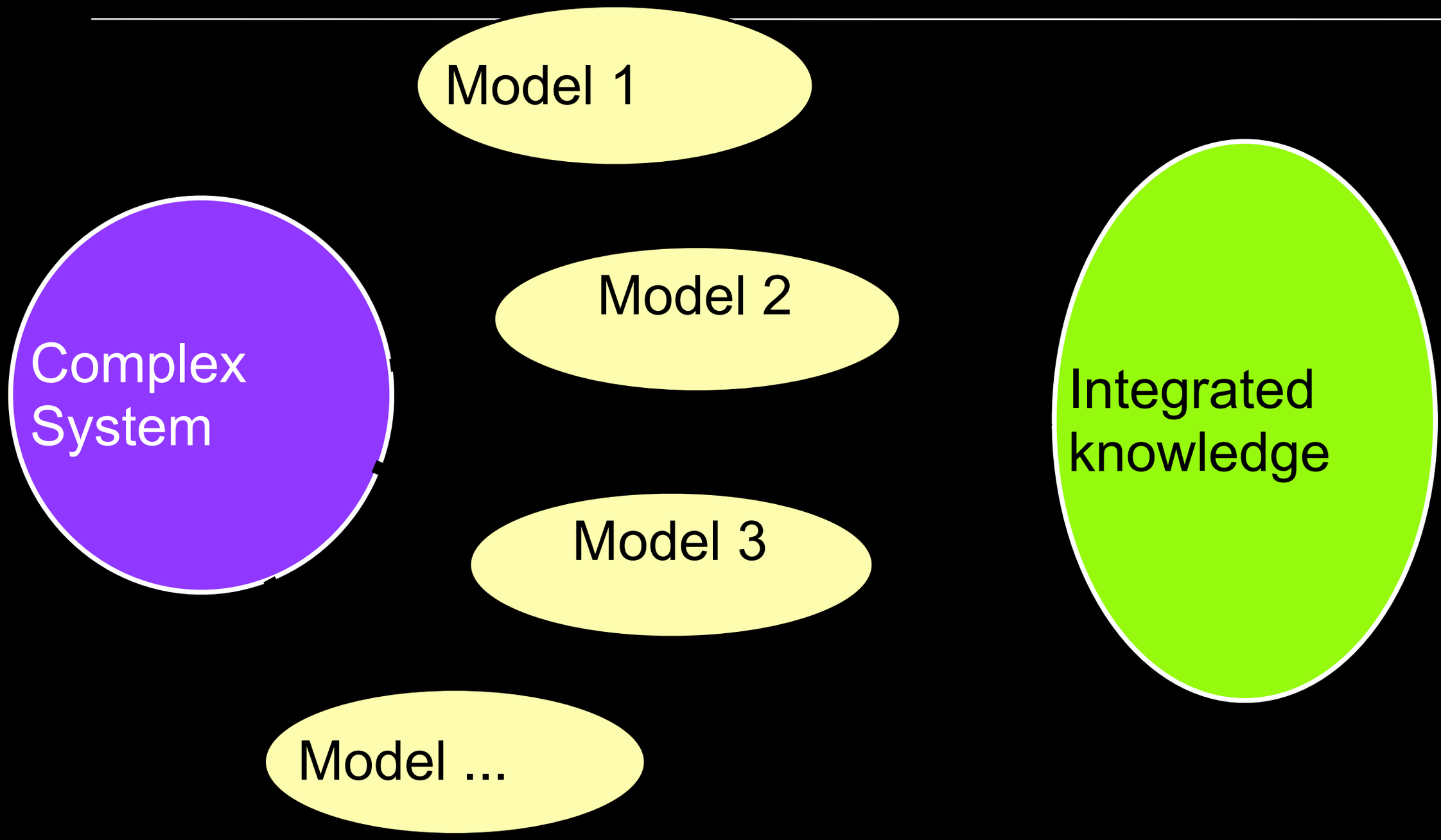
Tools for integral modeling - OMS



Tools for integral modeling - LMF

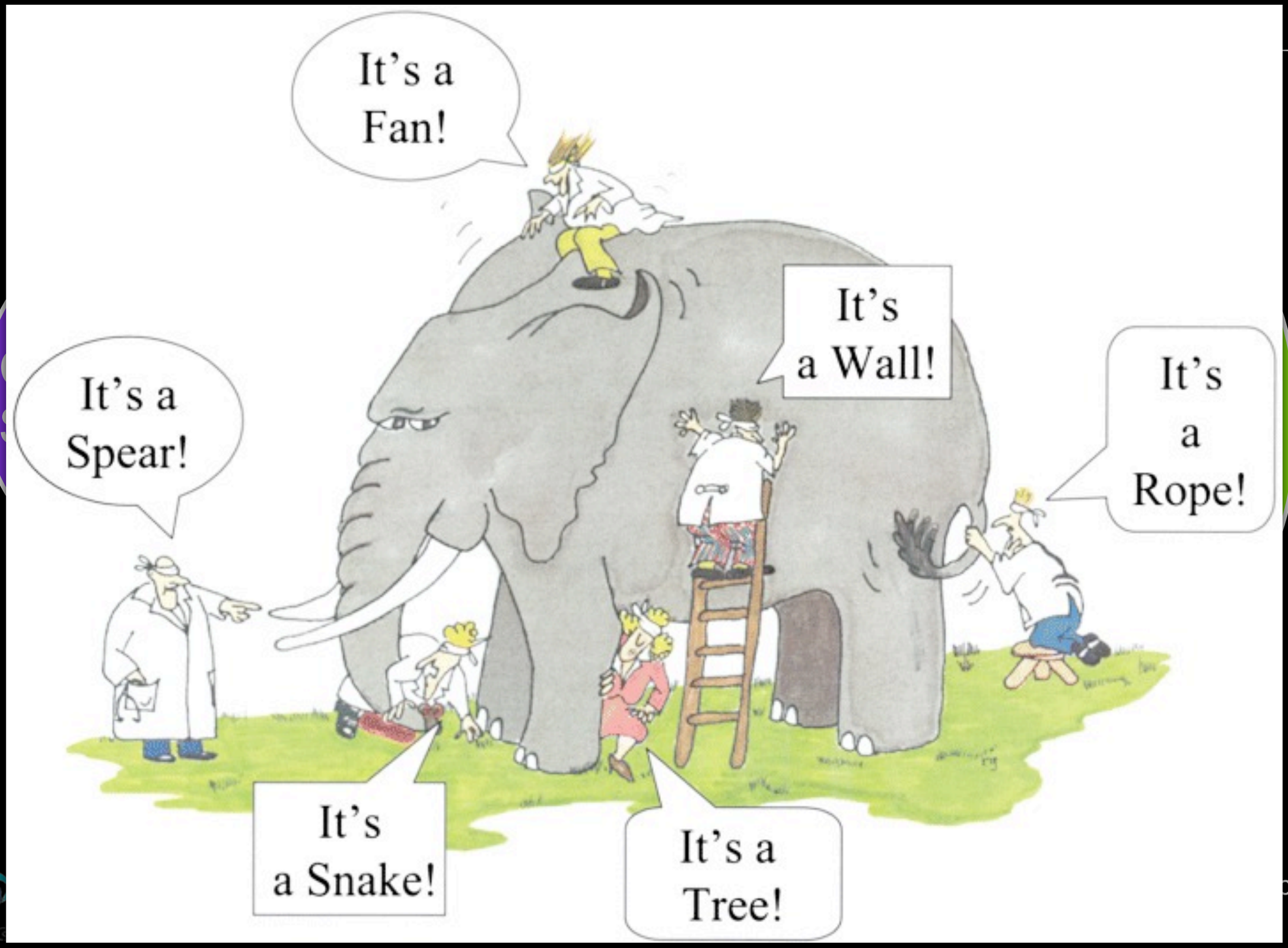


Integral models - Knowledge integration



Arkady Kryazhimskii, IIASA, personal communication

Integral models - Knowledge integration



cation

Big questions

- The tools help build models
- Can integrated (or integral) modeling help to deal with complexity or it only creates more complexity?
- The easier it is to build complex models, the more complex they get; software solutions tend to make models only more complex
- Complexity hides dynamics, increases model robustness
- Complex models are hard to test, to communicate, they are hard to trust
- “New” generated not necessarily from models, but from the modeling process
- Participatory modeling and decision making

Involve humans in modeling

Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

Involve humans in modeling

- Companion modeling, mediated modeling, shared vision planning…

Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

Involve humans in modeling

- Companion modeling, mediated modeling, shared vision planning…
- Participatory modeling is the process of incorporating stakeholders, including the public and decision-makers, into the modeling process

Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

Involve humans in modeling

- Companion modeling, mediated modeling, shared vision planning…
- Participatory modeling is the process of incorporating stakeholders, including the public and decision-makers, into the modeling process
- Soliciting information from stakeholders: integrating scientific knowledge with local knowledge

Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

Involve humans in modeling

- Companion modeling, mediated modeling, shared vision planning…
- Participatory modeling is the process of incorporating stakeholders, including the public and decision-makers, into the modeling process
- Soliciting information from stakeholders: integrating scientific knowledge with local knowledge
- Leveling the playing field: co-learning, co-understanding

Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

Involve humans in modeling

- Companion modeling, mediated modeling, shared vision planning…
- Participatory modeling is the process of incorporating stakeholders, including the public and decision-makers, into the modeling process
- Soliciting information from stakeholders: integrating scientific knowledge with local knowledge
- Leveling the playing field: co-learning, co-understanding
- Goal driven: you know how the model will be used

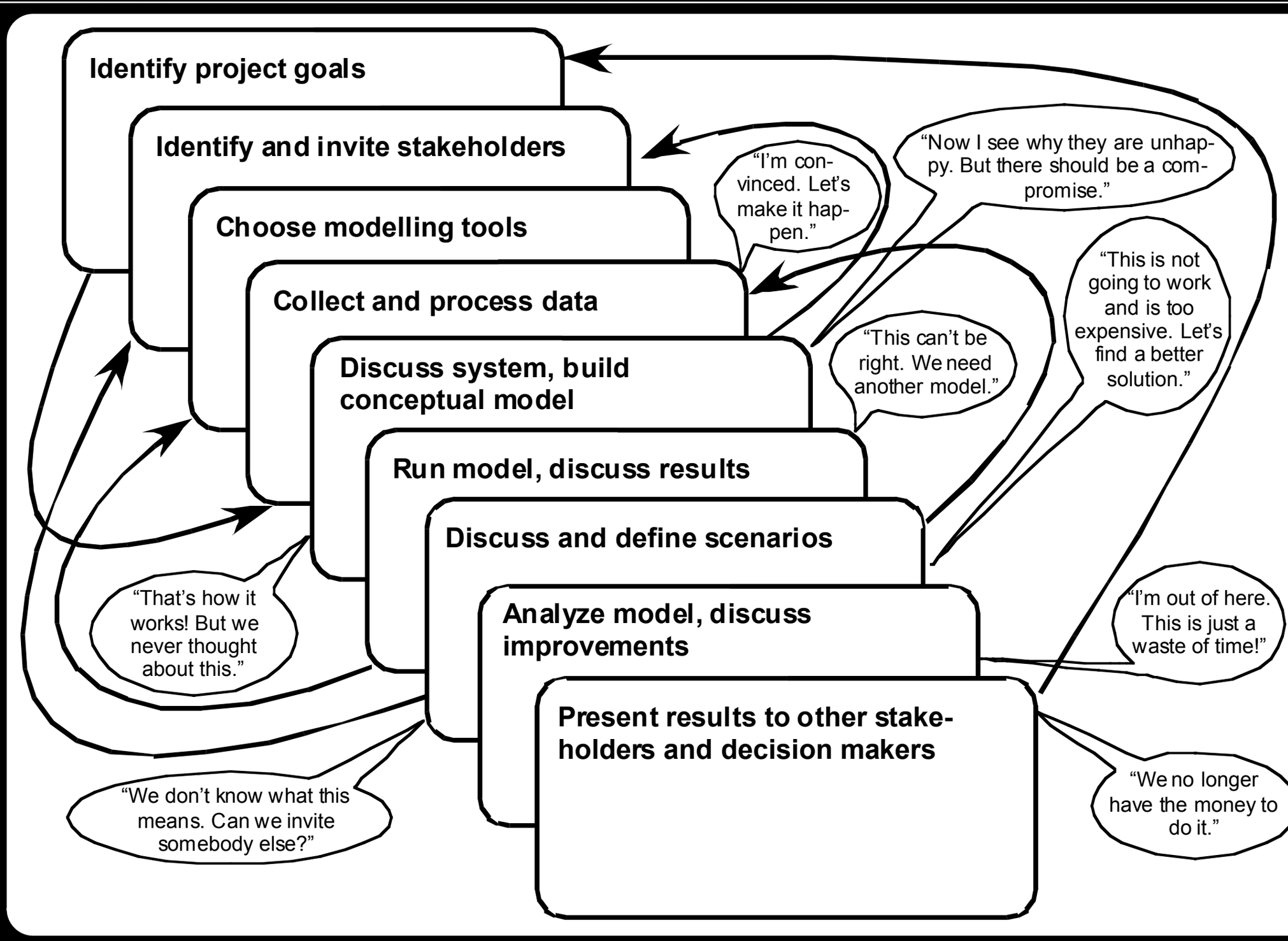
Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

Involve humans in modeling

- Companion modeling, mediated modeling, shared vision planning…
- Participatory modeling is the process of incorporating stakeholders, including the public and decision-makers, into the modeling process
- Soliciting information from stakeholders: integrating scientific knowledge with local knowledge
- Leveling the playing field: co-learning, co-understanding
- Goal driven: you know how the model will be used

Voinov, A.A., Gaddis, E., 2008. Lessons for Successful Participatory Watershed Modeling: A Perspective from Modeling Practitioners. Ecological Modelling: 216, p. 197–207.

The Process

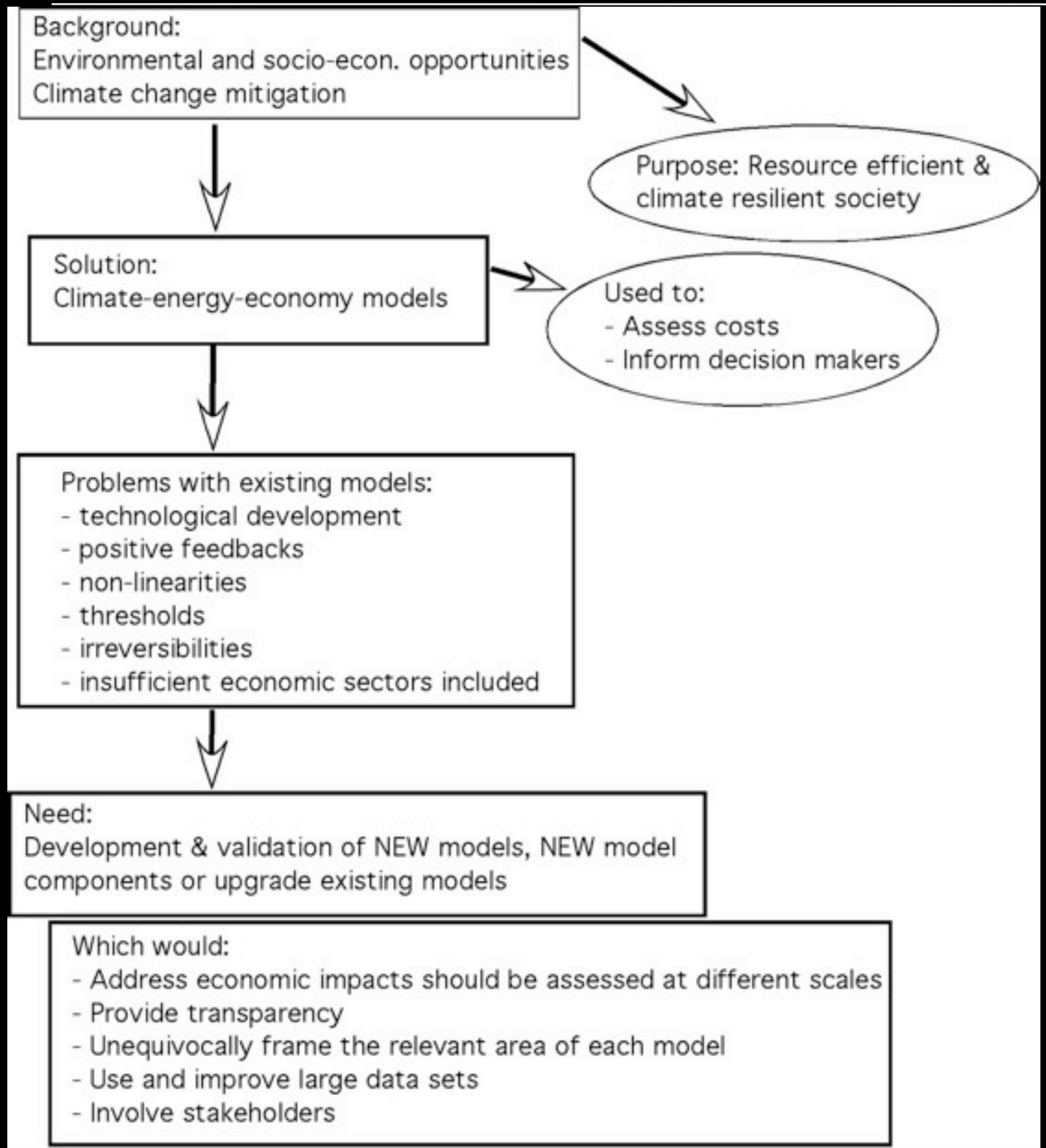


Voinov, A., and F. Bousquet. 2010. Modelling with stakeholders. *Environmental Modelling & Software* 25: 1268-1281.

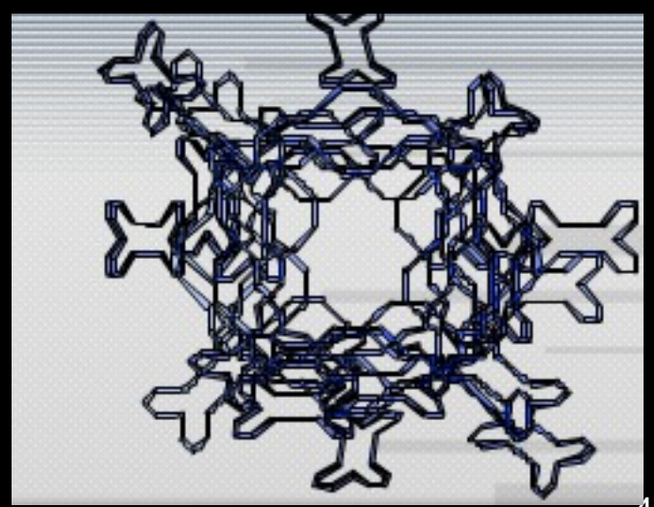
Integrating across model types

- Conceptual models - diagrams, charts, “rich pictures”, cognitive maps;
- Qualitative models - operating in terms of value sets, such as “more”, “less”, “good”, “better”, etc. - fuzzy logic;
- Quantitative models - computer simulations that operate in terms of equations, parameters, measured, observed rates and quantities
- How can we bring them all together?

FP7: COMPLEX

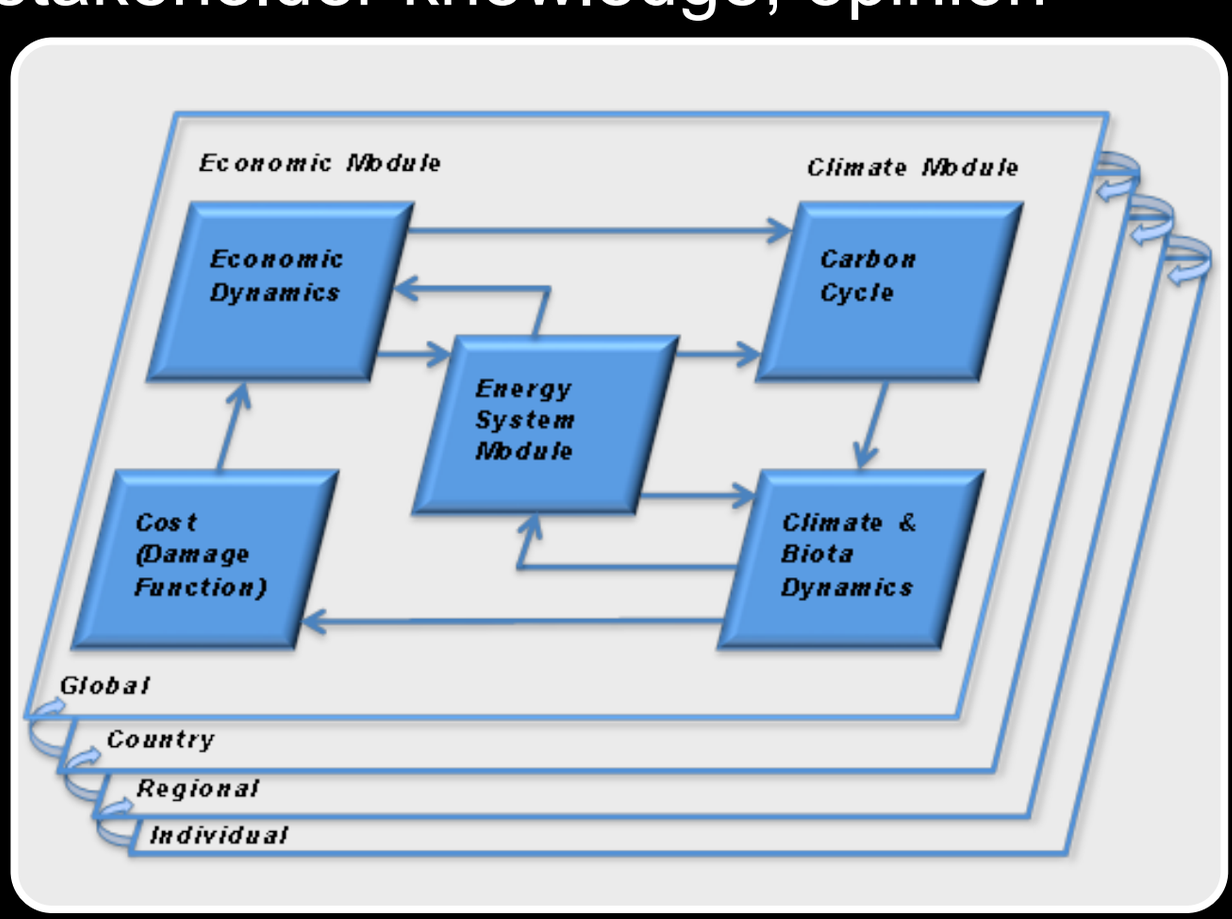


- Knowledge Based Climate Mitigation Systems for a Low Carbon Economy
- http://www.complex2050.eu

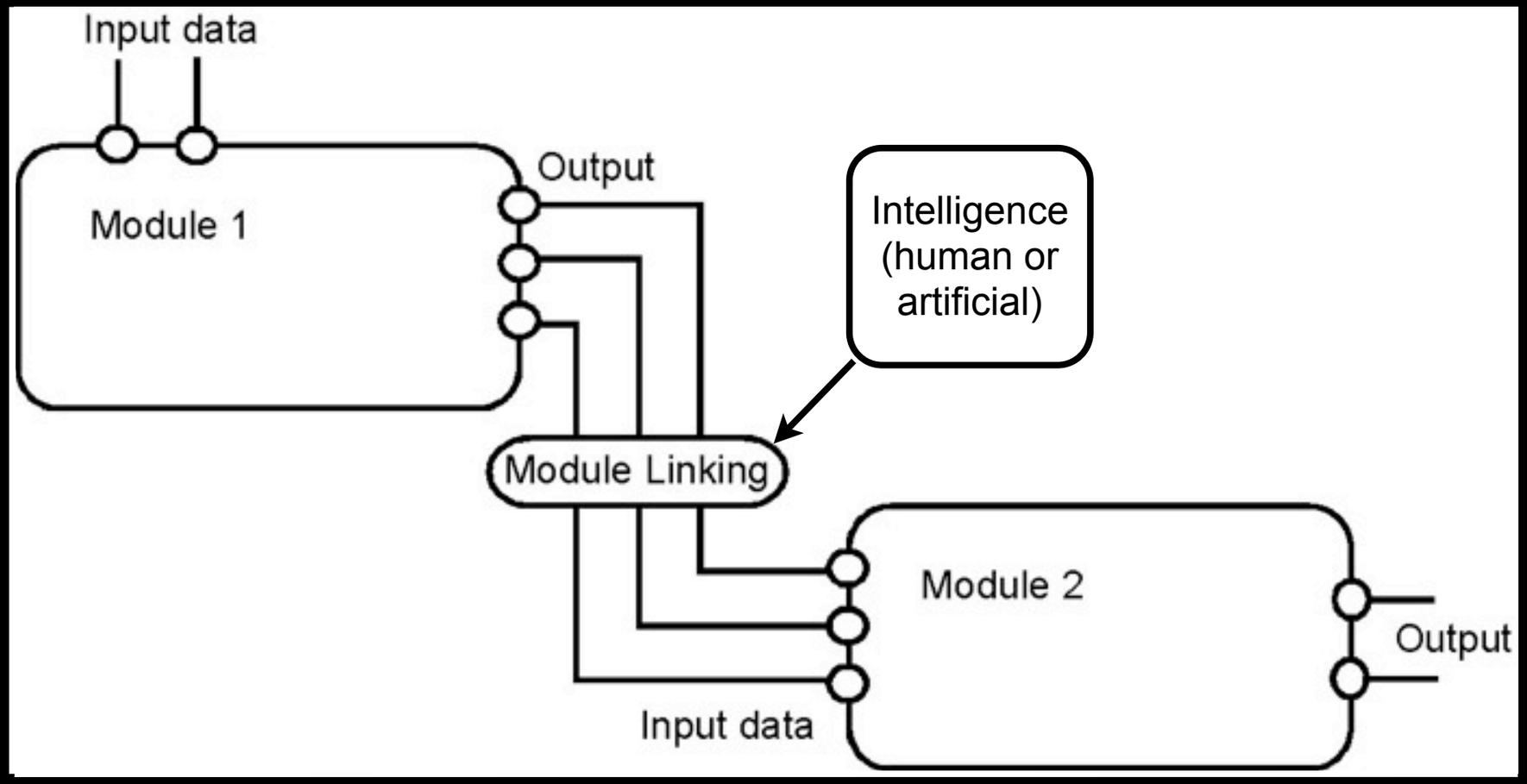


WP6: Integration of models

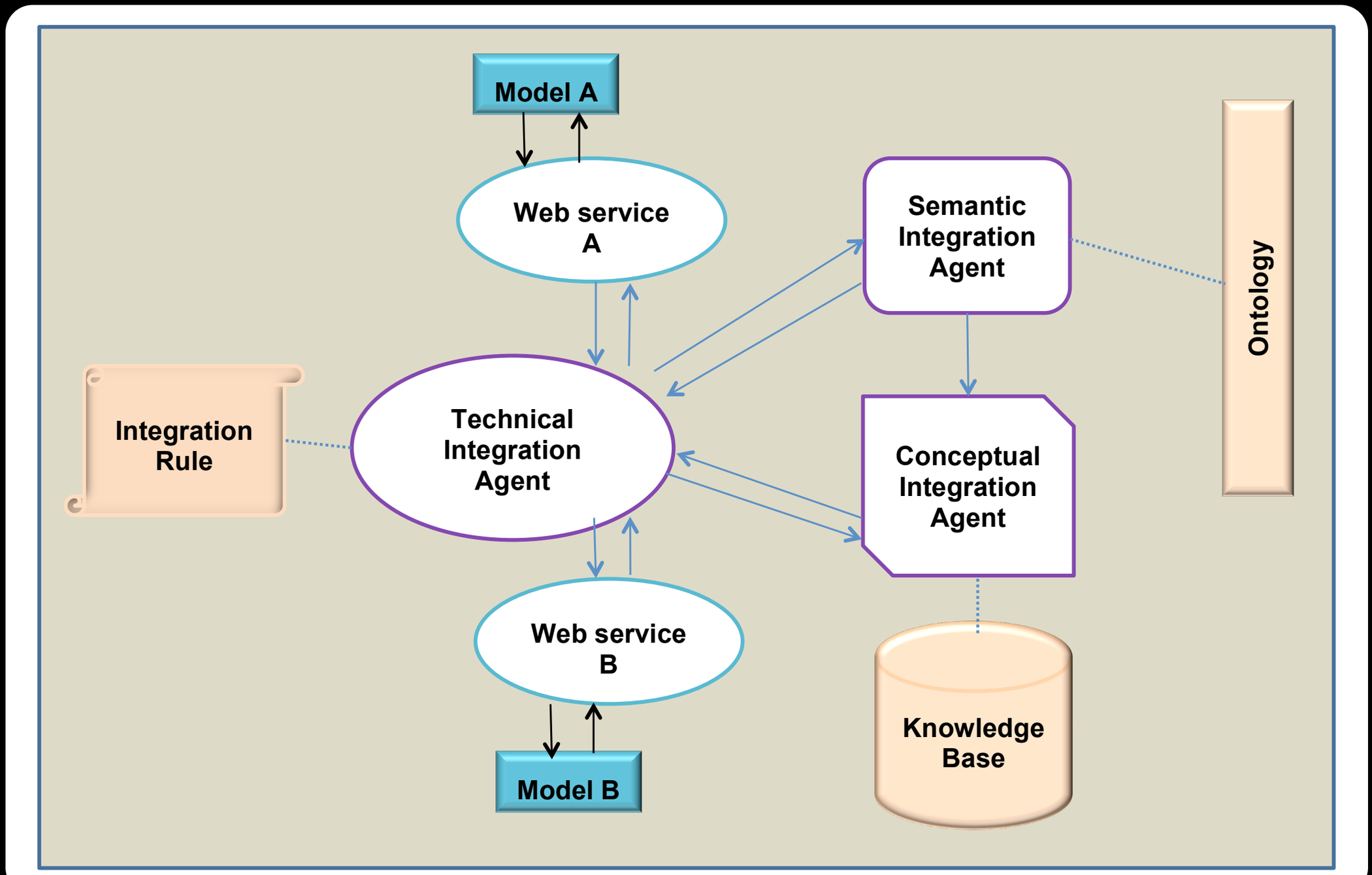
- Goal: build and analyze the hierarchy of models, which are developed and applied within this project and beyond
- Operate in a generalized ‘socio-environmental model space’ (empirical models, conceptual models, complex computer simulations, and data sets)
- Integrate qualitative models of stakeholder knowledge, opinion and scenarios
- Explore the different models along the complexity continuum to understand how information from more aggregated qualitative models can be transmitted to more elaborated and detailed quantitative simulations, and vice versa.



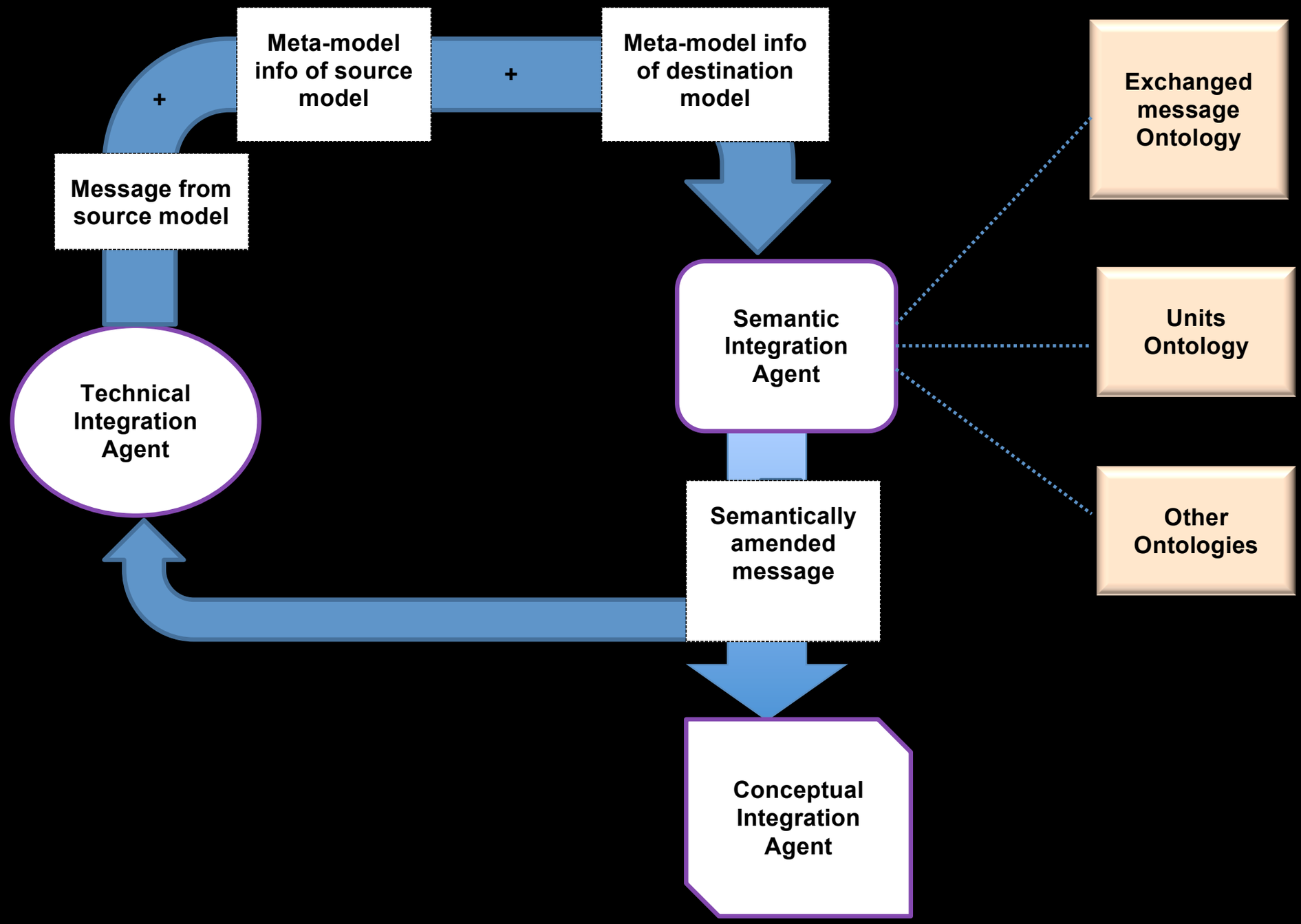
Model coupling



Technical integration agent



Semantic integration agent



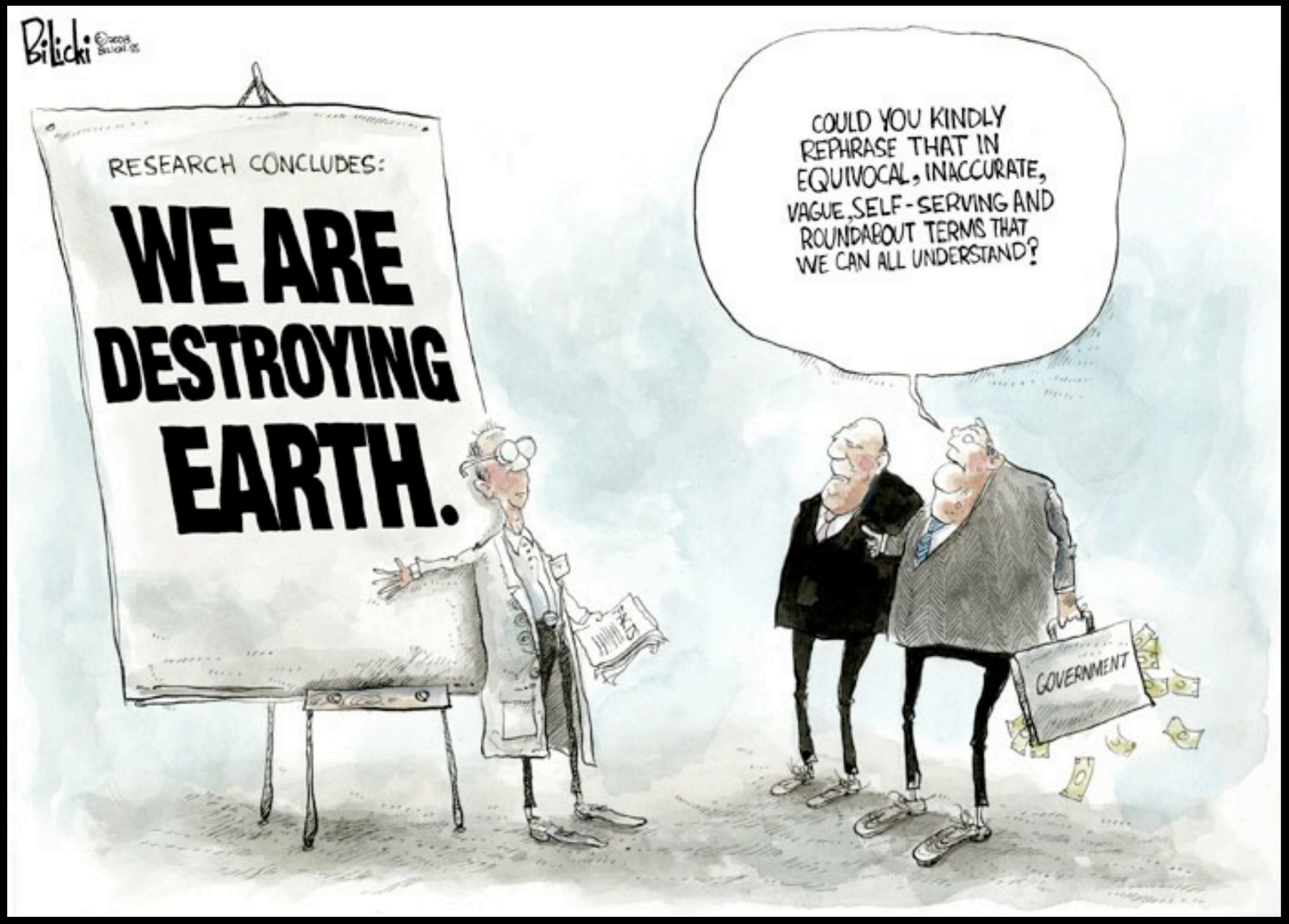
Technological imperative

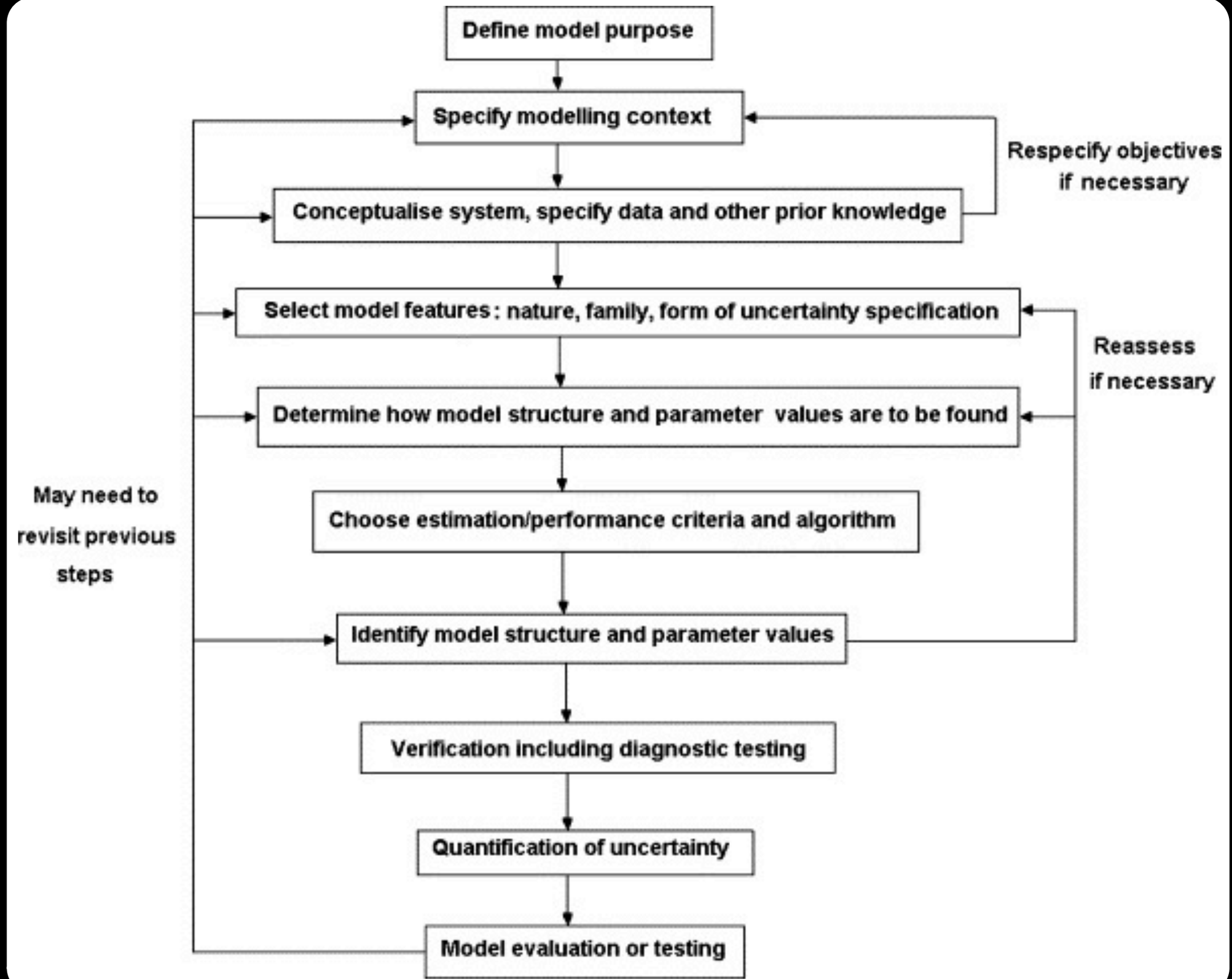
- Make models more like software and modeling more like science, less like art;
- Focus on standards for data, model input and output, and interfaces. Adopt existing and develop new ones;
- Develop standards for model conceptualization, formalization, and scaling;
- Semantic technologies;
- Ontology engineering;
- Metadata, markup languages;
- Require good documentation, including examples and test cases;
- Ensure transparency, portability, and reusability, and include procedures for version control, bug tracking, regression testing, and release maintenance.

Social imperative

- Collaborative, open source research and modeling
- Modeling with stakeholders
- Put the ‘user’ upfront, understand their needs and behavior
- Toolboxes and model repositories for participatory modeling
- Integrating conceptual models
- Integrating numbers with ideas
- Visualizations and perceptions - learn from media and commerce

- Our limiting factor today is communication
- We need to learn to speak the same language
- Models can help if used to communicate





A.J. Jakeman, R.A. Letcher, J.P. Norton, 2006. Ten iterative steps in development and evaluation of environmental models, Environmental Modelling & Software, Volume 21, Issue 5, p. 602-614

Role of applied science (modeling)

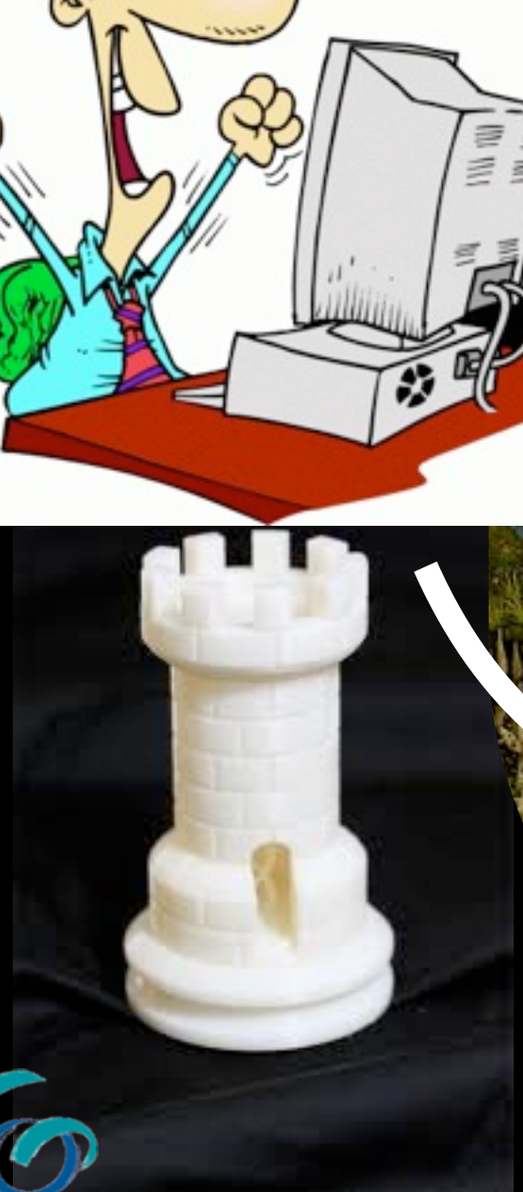
Role of applied science (modeling)

Role of applied science (modeling)

Role of applied science (modeling)

Role of applied science (modeling)

Role of applied science (modeling)



Role of applied science (modeling)

Role of applied science (modeling)

Role of applied science (modeling)

Seven commandments for a socio-environmental modelling agenda

Seven commandments for a socio-environmental modelling agenda

- Stop pretending that applied science and models are always objective and value neutral – they are not. Acknowledge implicit decisions and assumptions, document and communicate them.

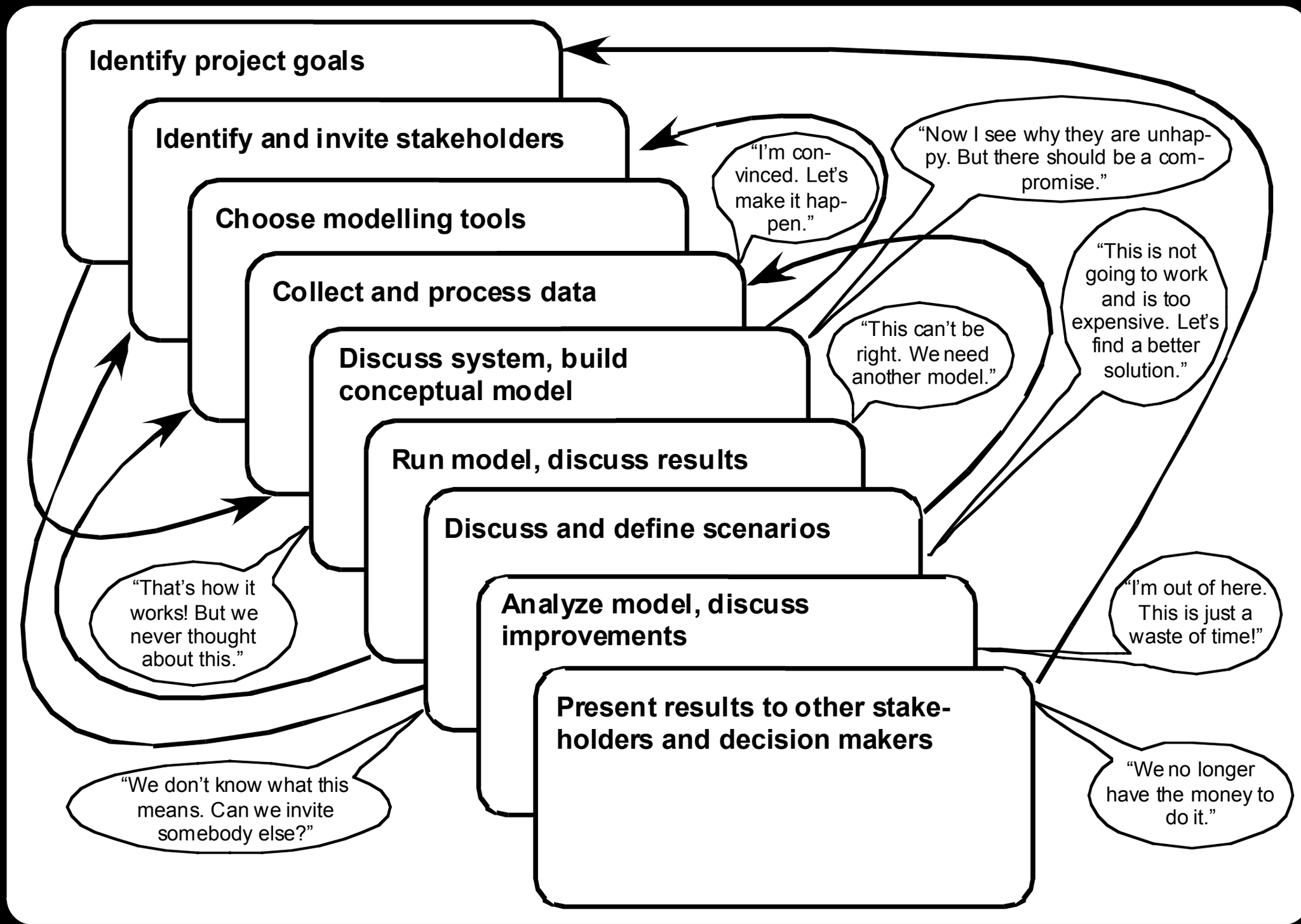
Seven commandments for a socio-environmental modelling agenda

- Stop pretending that applied science and models are always objective and value neutral – they are not. Acknowledge implicit decisions and assumptions, document and communicate them.
- Make it clear that scientific values are based on facts and knowledge, which makes them transparent.

Seven commandments for a socio-environmental modelling agenda

- ! Stop pretending that applied science and models are always objective and value neutral Ð they are not. Acknowledge implicit decisions and assumptions, document and communicate them.
- ! Make it clear that scientific values are based on facts and knowledge, which makes them transparent.
- ! Scientific values are not set in stone Ð they can change when new knowledge becomes available.

The Process


Identify project goals
Identify and invite stakeholders
Choose modelling tools
Collect and process data
Discuss system, build conceptual model
Run model, discuss results
Discuss and define scenarios
Analyze model, discuss improvements
Present results to other stake-holders and decision makers
"I'm con-vinced. Let's make it hap-pen."
"Now I see why they are unhap-py. But there should be a com-promise."
"This is not going to work and is too expensive. Let's find a better solution."
"This can't be right. We need another model."
"That's how it works! But we never thought about this."
"We don't know what this means. Can we invite somebody else?"
"I'm out of here. This is just a waste of time!"
"We no longer have the money to do it."

theguardian

News | Sport | Comment | Culture | Business | Money | Life & style

Comment is free

Scientists have a moral obligation to take action on climate change

Calling on all scientists to refrain from public advocacy and leadership is wrong. We are in a global crisis, and the scientific fraternity has an ethical obligation to act

Dan Cass
theguardian.com, Thursday 15 August 2013 05.50 BST

Jump to comments (…)

'We need some scientists to show social leadership, not just scientific leadership'. Photograph: Getty/Joe Raedle

Conclusions

- Beware of integronsters
- Keep the data in and make it part of the integration process. Treat data as models
- Think about calibration. Two-way coupling can be problematic for calibration
- Integral models may be more appropriate than integrated models
- Are we creating too much complexity and is too much complexity causing too much uncertainty?
- How to scale up and down across structural complexity?
- How to engage and provide for stakeholders?

Conclusions (cont.)

- The stakeholder (user, customer) is the ultimate judge of the ‘goodness’ of your model (system)
- Stakeholders have to be ‘educated’ to appreciate your model (system)
- The more complex your model (system) the harder it is for the stakeholders to appreciate it, the more you need to care about involving them as much as possible and as early as possible