SmartCAD Advisory Board Meeting, 2016

SmartCAD: Guiding Engineering Design with Science Simulation

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This work is supported by the National Science Foundation (NSF) under grant numbers 1348530 & 1503196. Any opinions, findings, and conclusions or recommendations expressed in this material, however, are those of the authors and do not necessarily reflect the views of the NSF.

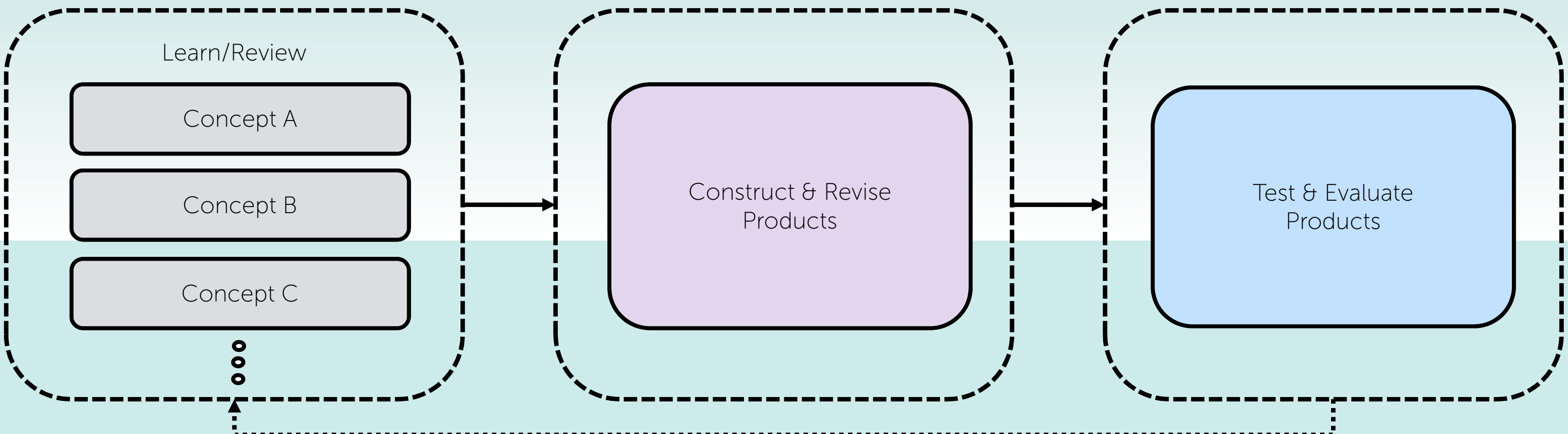
What problems are we trying to solve?

Engineering design is a process. **Summative assessment based on analyzing final products is too little too late**. We want to help students while they are on it. Continuous formative feedback is a key. But it is impossible for teachers to keep track of every move of every student.

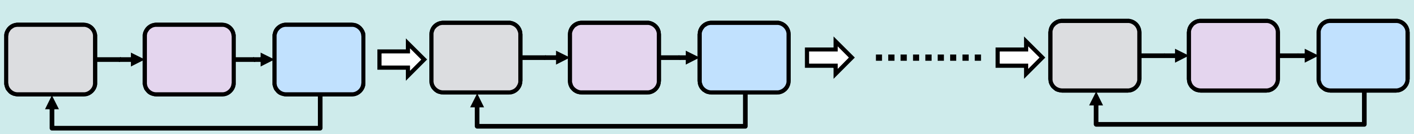
Fair analysis of complex design may also be too time-consuming as it needs to include many fine-grained, domain-specific aspects.

Computers can do all these on human's behalf!

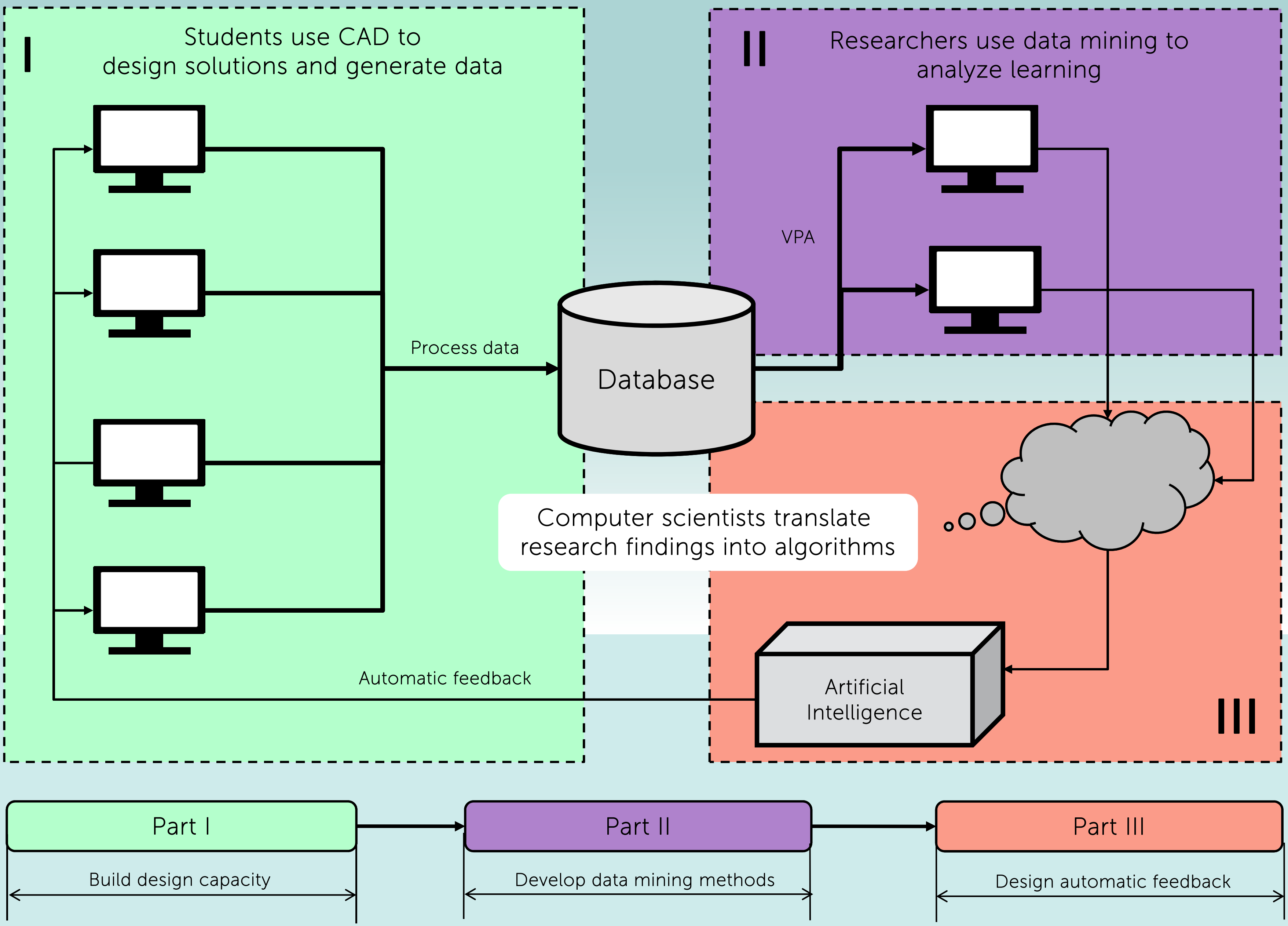
Common Approach
Coarse-Grained, Delayed Feedback



New Approach
Fine-Grained, Real-Time Feedback



The SmartCAD Vision



Part I

Building Design Capacity
to Support a Variety of Engineering Projects Related to Energy

The Energy3D SmartCAD program: A simulated engineering design environment

An open lab for anyone to conduct data-intensive research on engineering design

- Architectural engineering
- Solar engineering
- Energy engineering
- Urban planning
- …

http://energy3d.concord.org

Design Capacity of Energy3D

There is no room for complacency in CAD as it must model reality accurately.

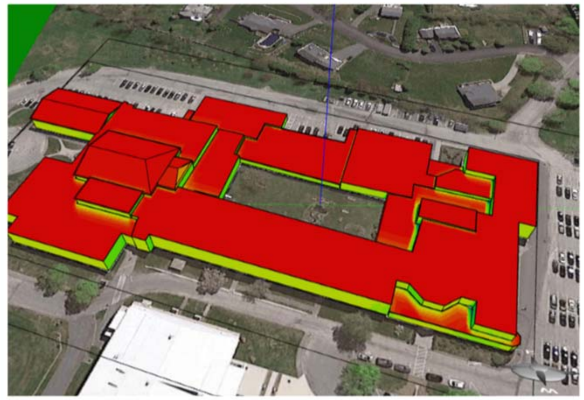
Environmental modeling
- Google Maps integration
- Weather datasets (NREL's TMY, TMY3*)
- Geothermal heat transfer

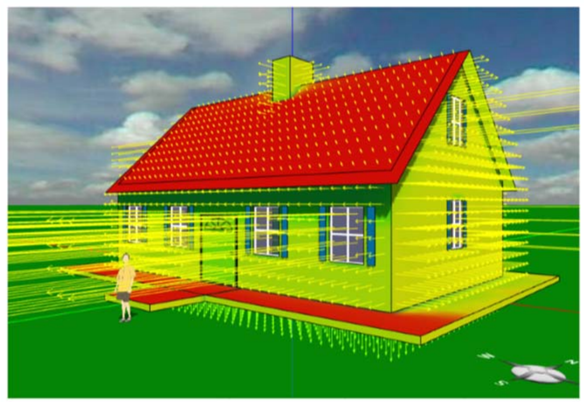
Solar modeling
- Photovoltaics (PV)
  - Rooftop PV solar systems
  - Ground-mounted solar panel arrays
  - Solar canopies
  - Solar trackers (HSAT, VSAT, AADAT)
- Concentrated solar power (CSP)
  - Solar power tower
  - Parabolic trough*
  - Compact linear Fresnel reflector*
- Solar updraft tower*

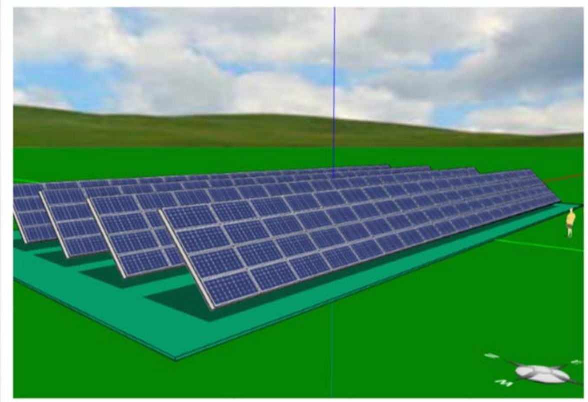
Building modeling
- Building envelope design
- HVAC system
- Passive solar
- Landscape

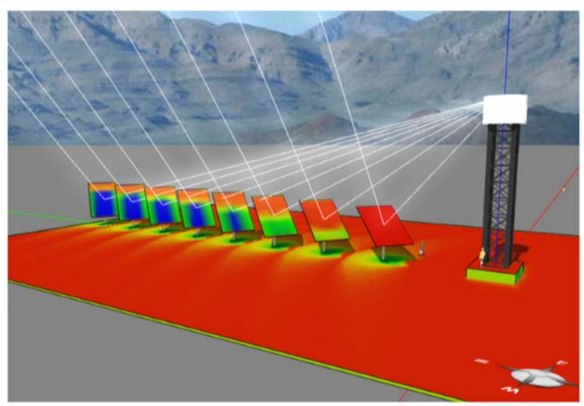
Financial modeling
- Cost-benefit analysis
- Net metering
- Community solar

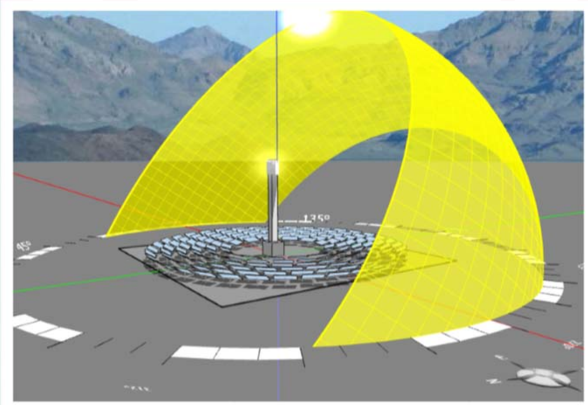
** Under construction*





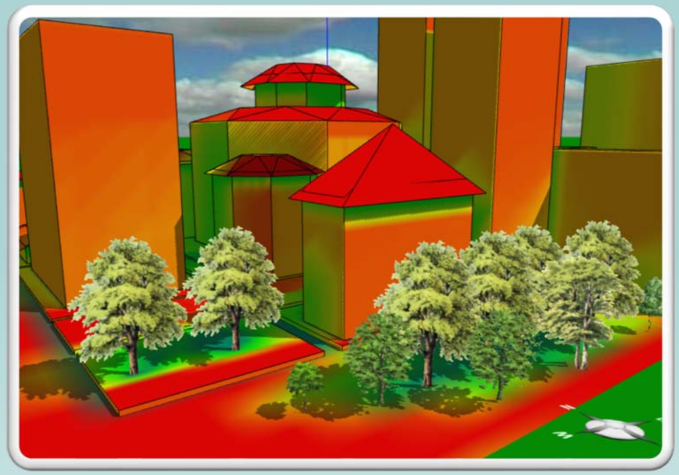






Engineering projects supported by Energy3D

Design an Energy-Plus Home
Design a home building that generates more renewable energy than it consumes over the course of a year

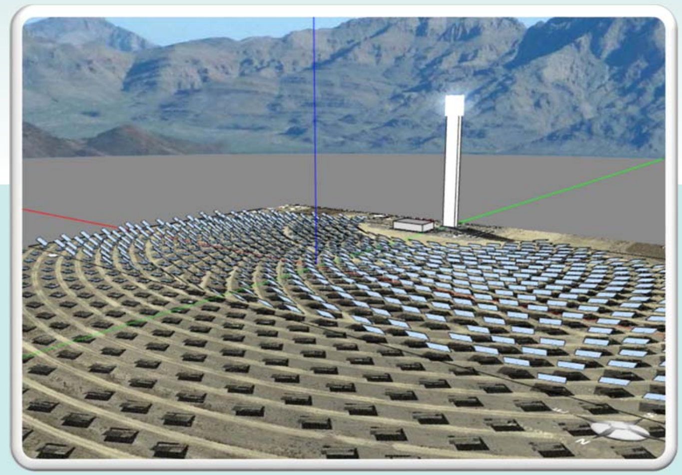


Design a City Block
Design a city block with high-rise buildings that have optimal solar access and minimal impacts on existing buildings

Solarize Your School
Design a solar power solution (e.g., rooftop solar panel arrays or solar canopies over parking lots for your school

Solarize Your House
Design solar panel arrays for your house that has the best cost effectiveness

Design a Solar Farm
Design a solar farm for a brownfield or landfill in your town



Design a Solar Power Tower
Design a utility-scale concentrated solar power plant

Part II

Building Data Mining Capacity
to Support Computational Analysis of Student Design

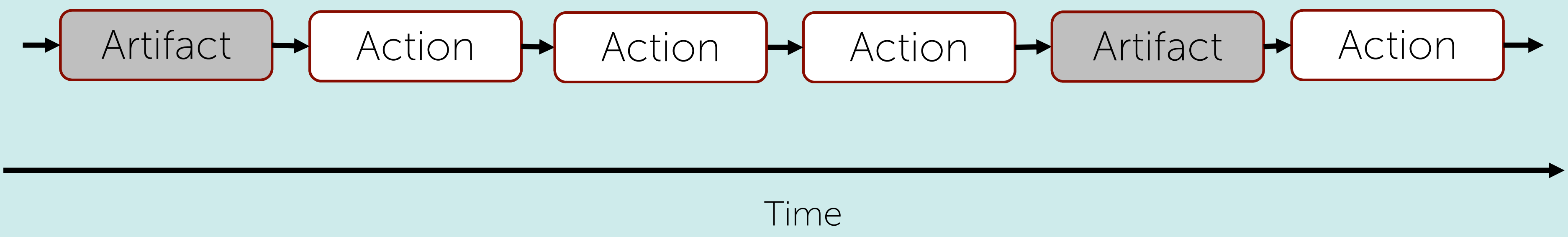
What data do we mine?

Category I: Artifact mining
Data sources are results from analyses/simulations/virtual tests of designs based on geometric, physical, and financial modeling.

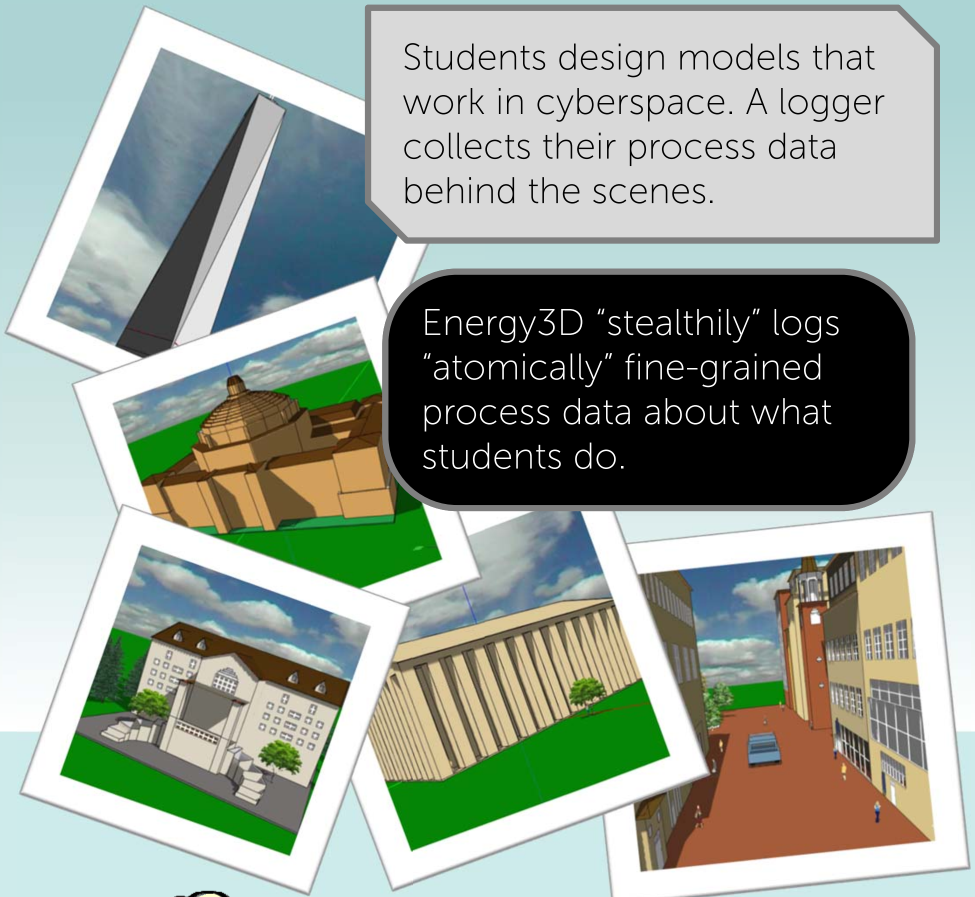
Category II: Action mining
Data sources are actions that lead to changes of artifacts or not (e.g., an analysis informs design but does not change the solution per se).

A breakdown of engineering design process

(intertwined sequences of actions and artifact changes)



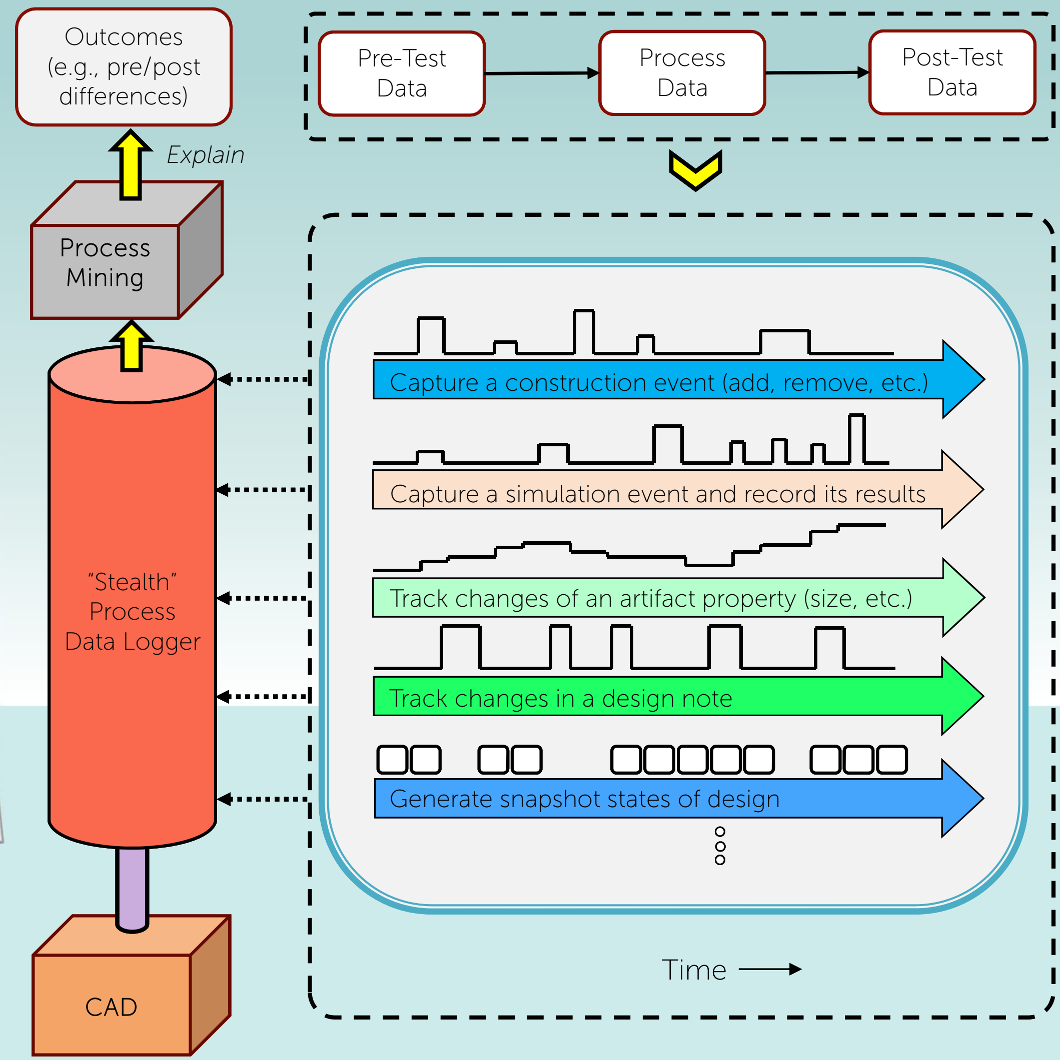
Collecting empirical “atomic” process data



Students design models that work in cyberspace. A logger collects their process data behind the scenes.

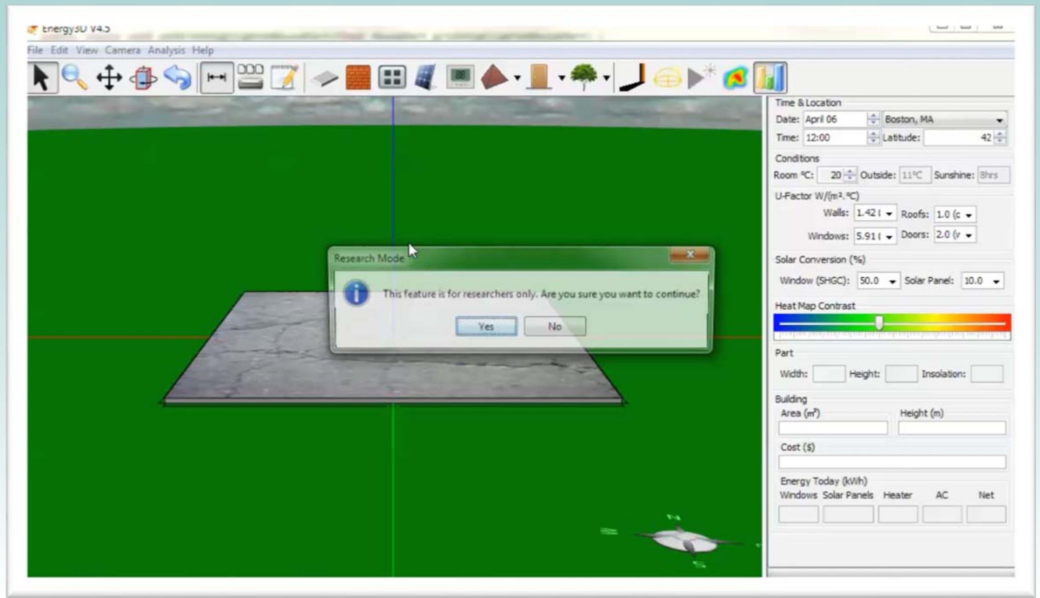
Energy3D “stealthily” logs “atomically” fine-grained process data about what students do.

Our invention: A data logger based on Undo Manager and Track Change (more structured than mouse clicks)



Design replay

Reconstruct a design process from the data log and play it back like running a slide show and post-process it to extract information as needed



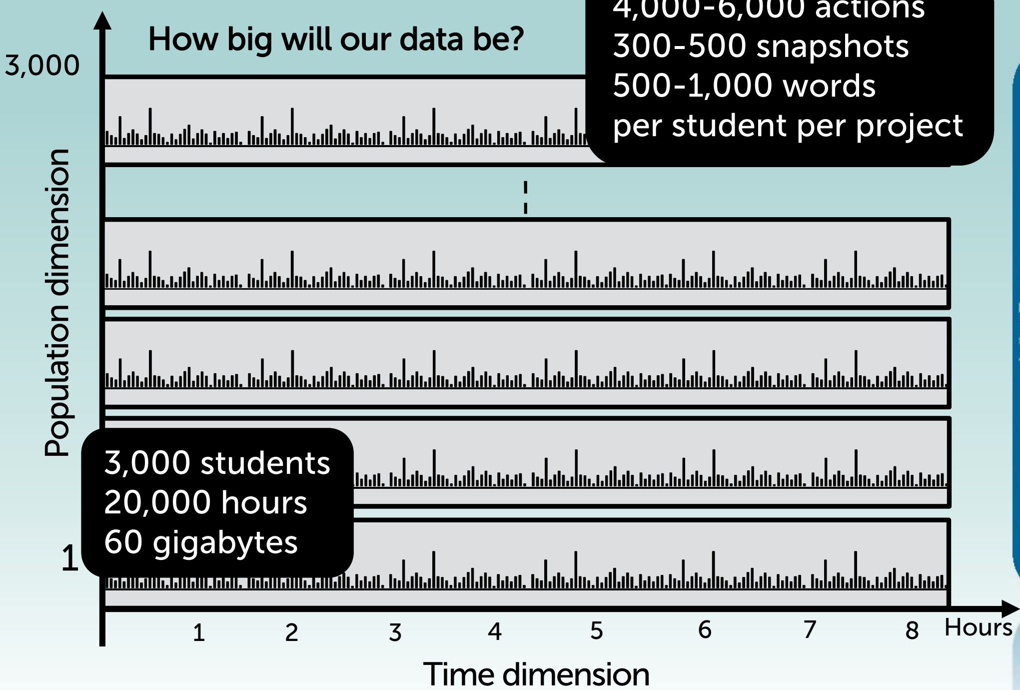
(Embedded video)

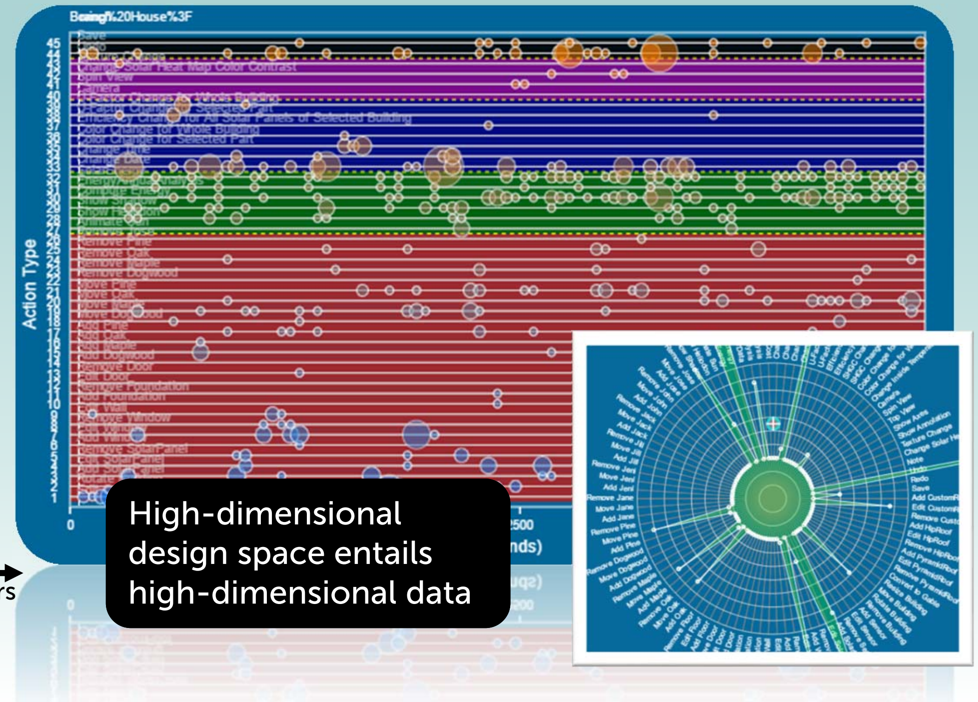
Compare with screencast, recording is based on events, not lapse of time.
(i.e., no event, no record.)

High ratio of lossless compression!

Data-intensive research

(aka "big data" – the fourth paradigm of science)





As of 2016: 1,000+ students' data will be in our repository.

What can we do with these data?

What can we find from these data?

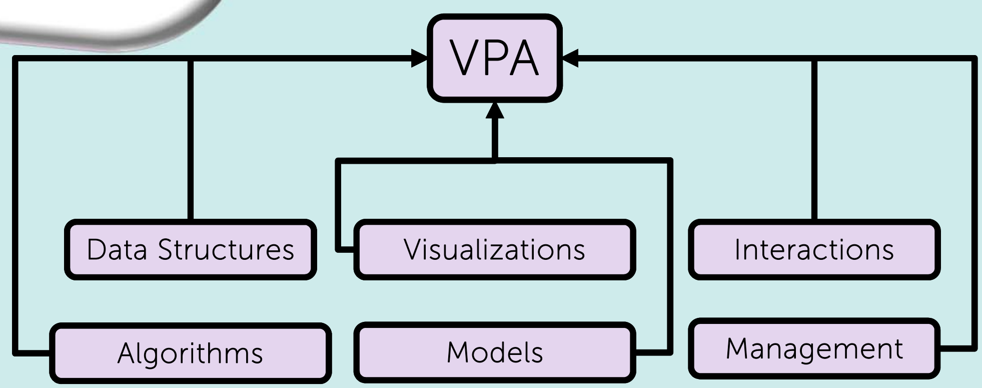
Visual Process Analytics (VPA)

Let's start with visualizing the data.

VPA is a cloud-based data mining platform that supports research on student learning through using complex tools to solve complex problems.

http://vpa.concord.org

- Process mining
- Process modeling
- Process discovery
- Conformance analysis
- Statistical analysis
- ……



VPA supports multiple representations of data

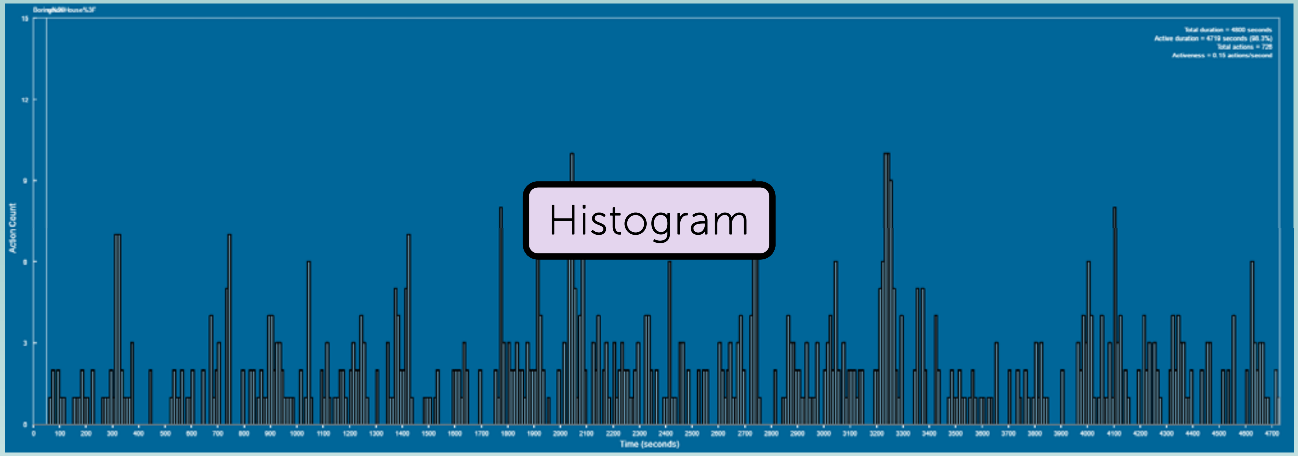
Time series visualization

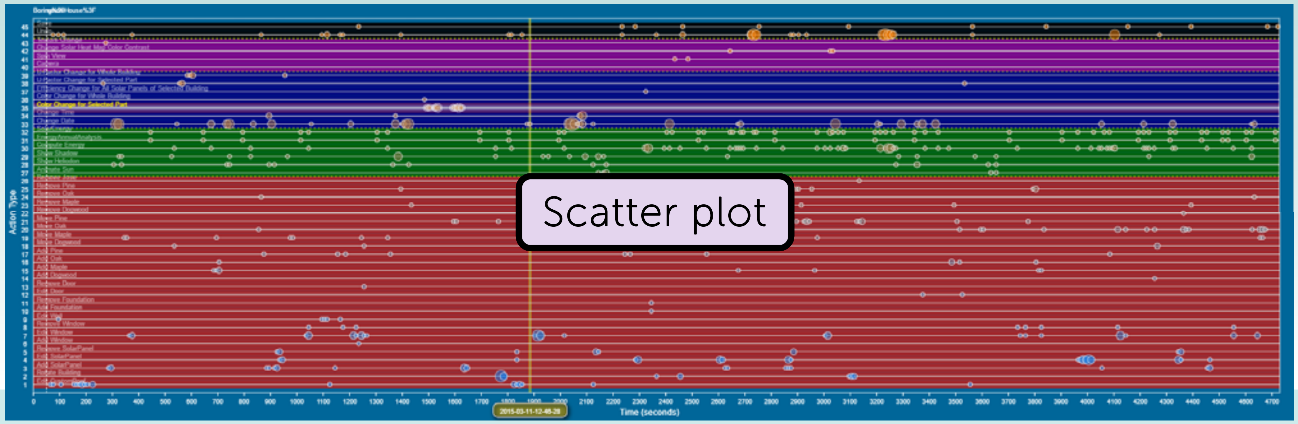
Histogram shows the total number of actions within each time bin

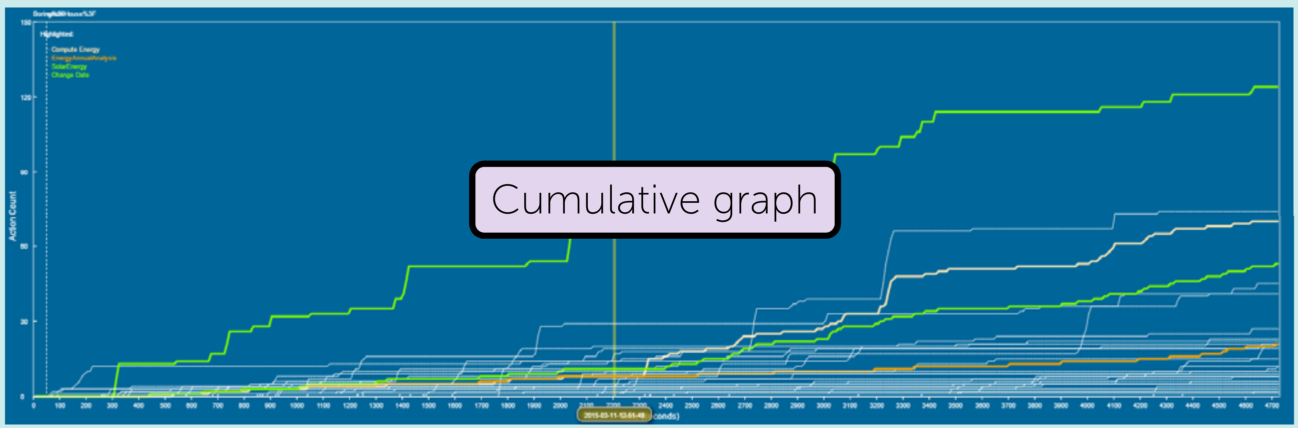
Scatter plot shows the number of actions of different types within each time bin

Cumulative graph shows the growth of the total number of actions of different types

Each kind of visualization represents a different view of the data and a different aspect of the process.

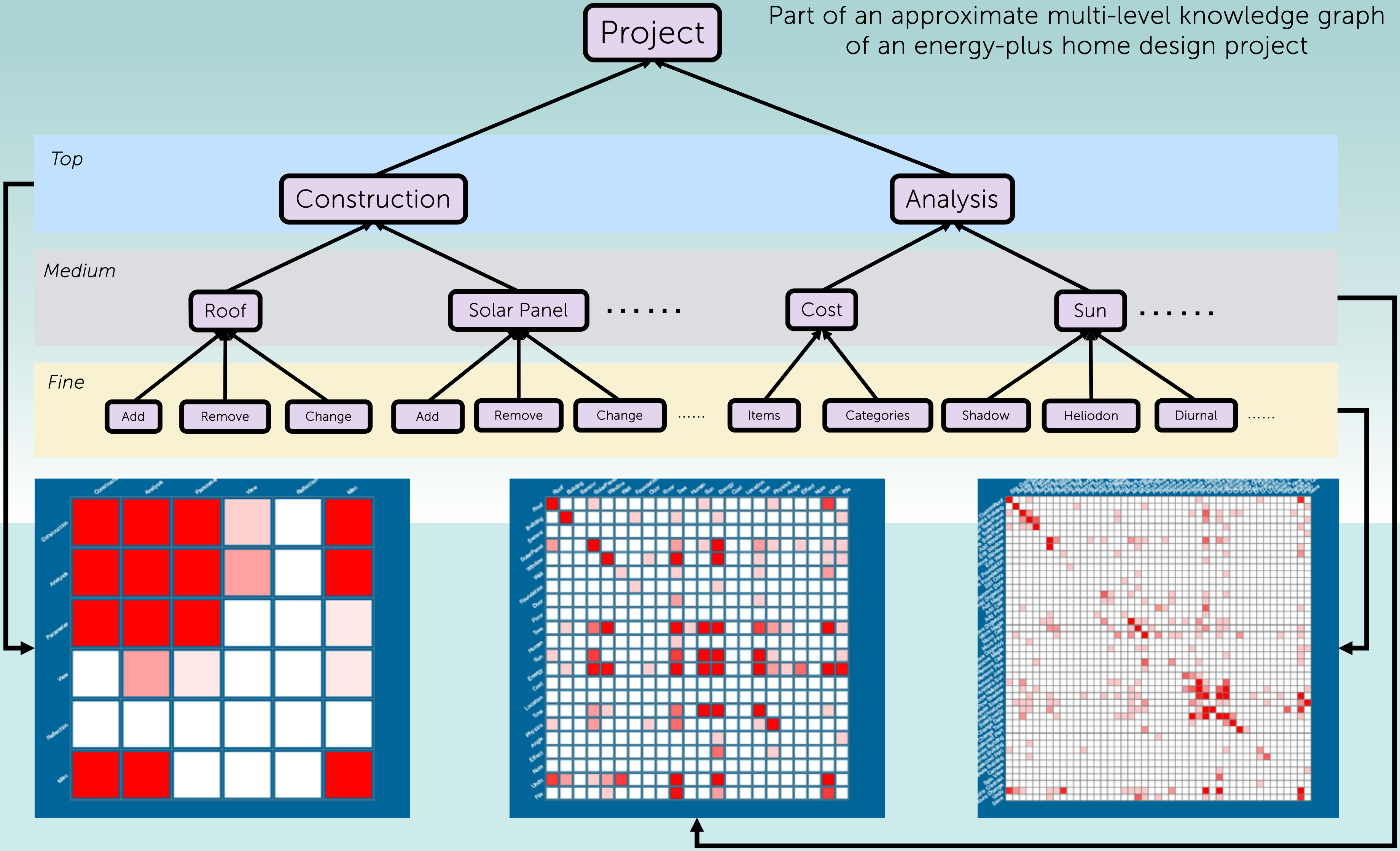






VPA supports multiple granularity of visualization

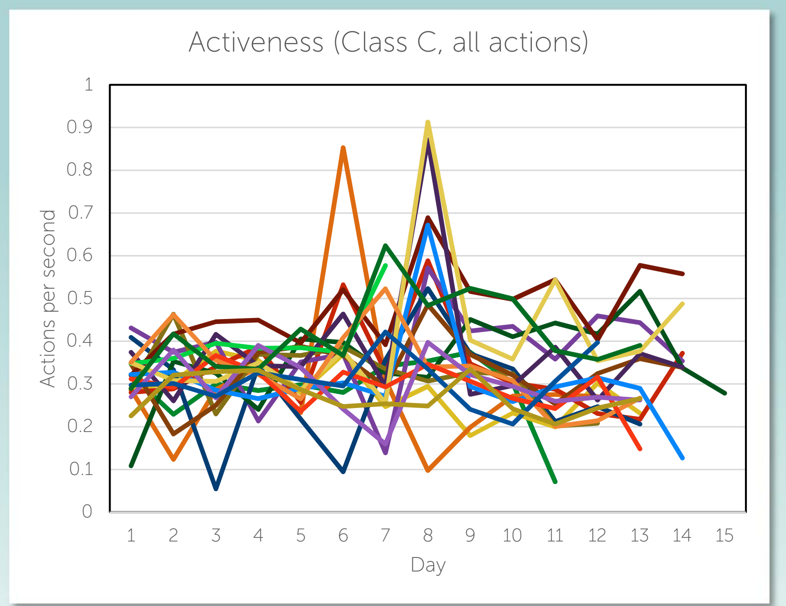
Coarse-grained vs. fine-grained analysis across knowledge graphs

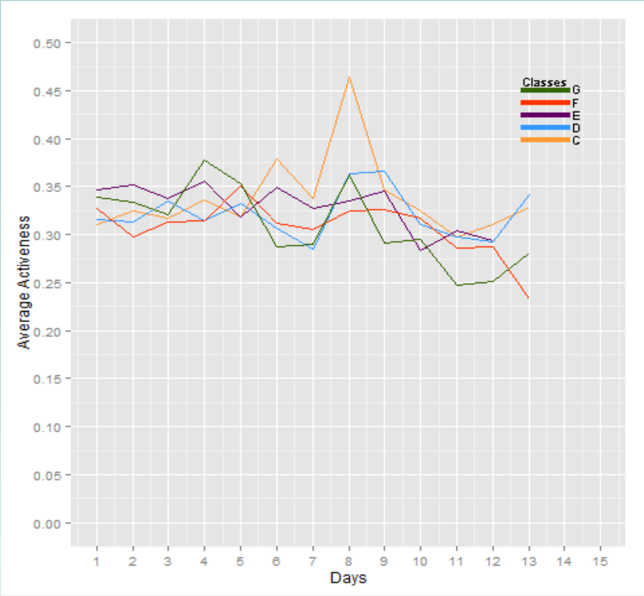


Heat maps of task transitions (to be described later)

VPA supports data collection and export

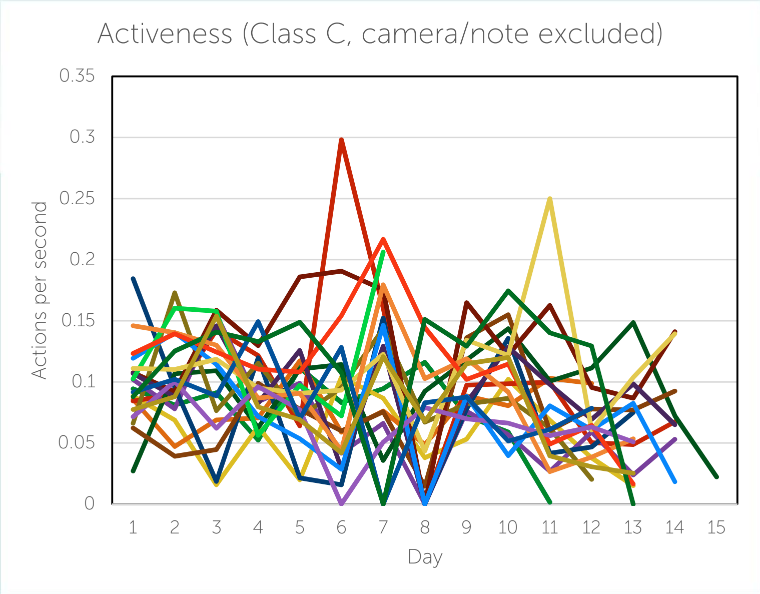
Mined results can be collected and exported for further analyses.

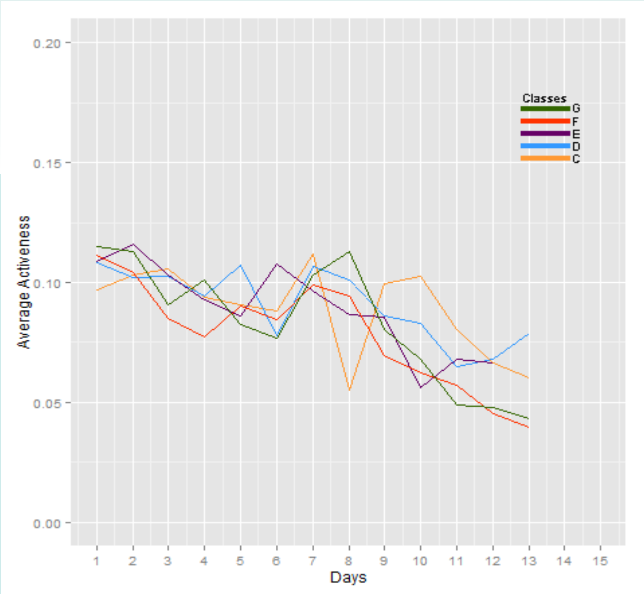




The change of the average activeness of five classes of students over time

(a total of 110 students)





The change of average activeness of five classes of students after filtering out 3D rotation and note taking, showing a gradual decrease over the course of two weeks.

Excel

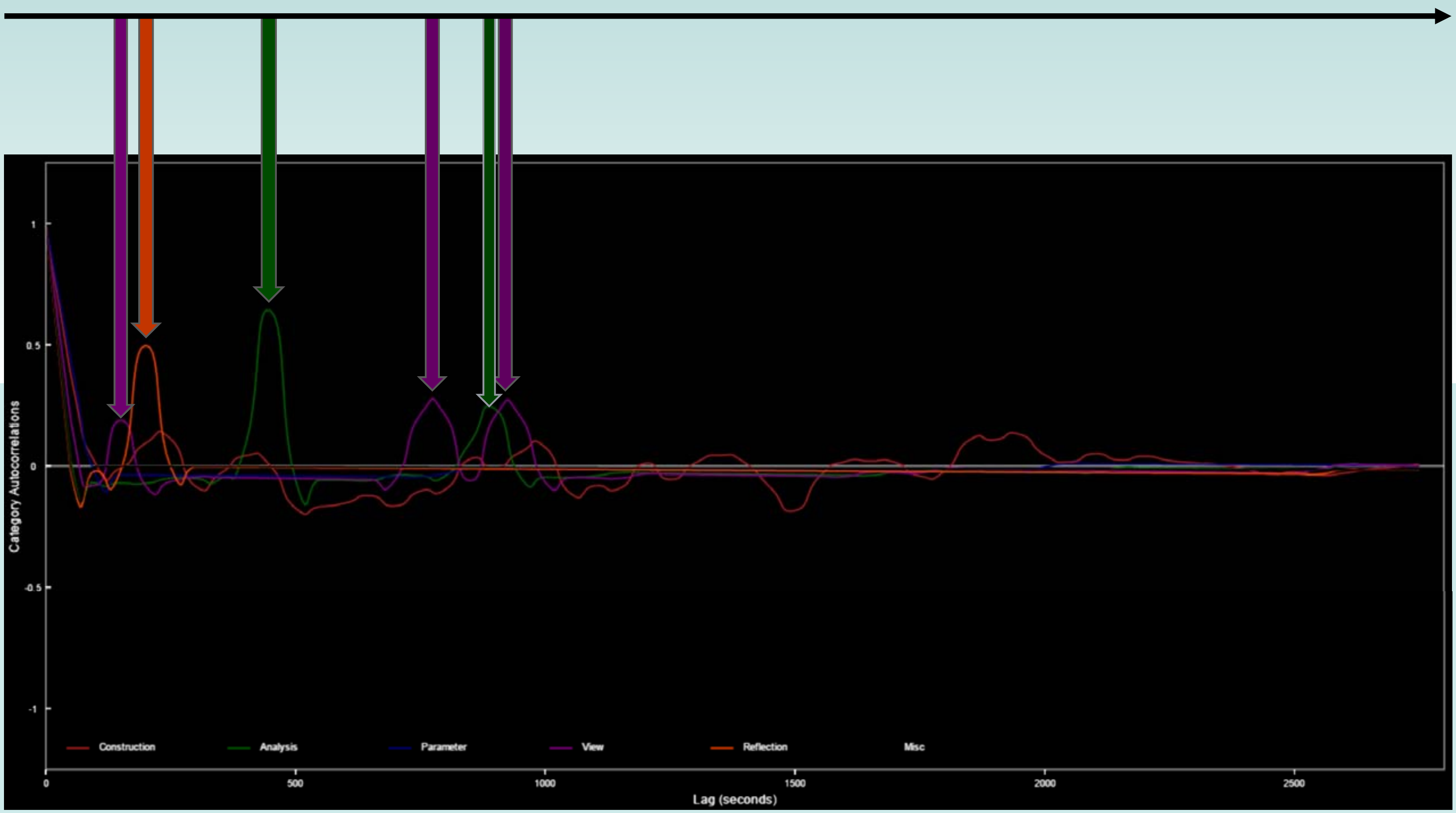
RStudio

VPA tool: Time correlation functions

Correlograms show repeating patterns of behavior: After how long, on average, do students repeat certain types of actions (an indicator of possible design iteration)?

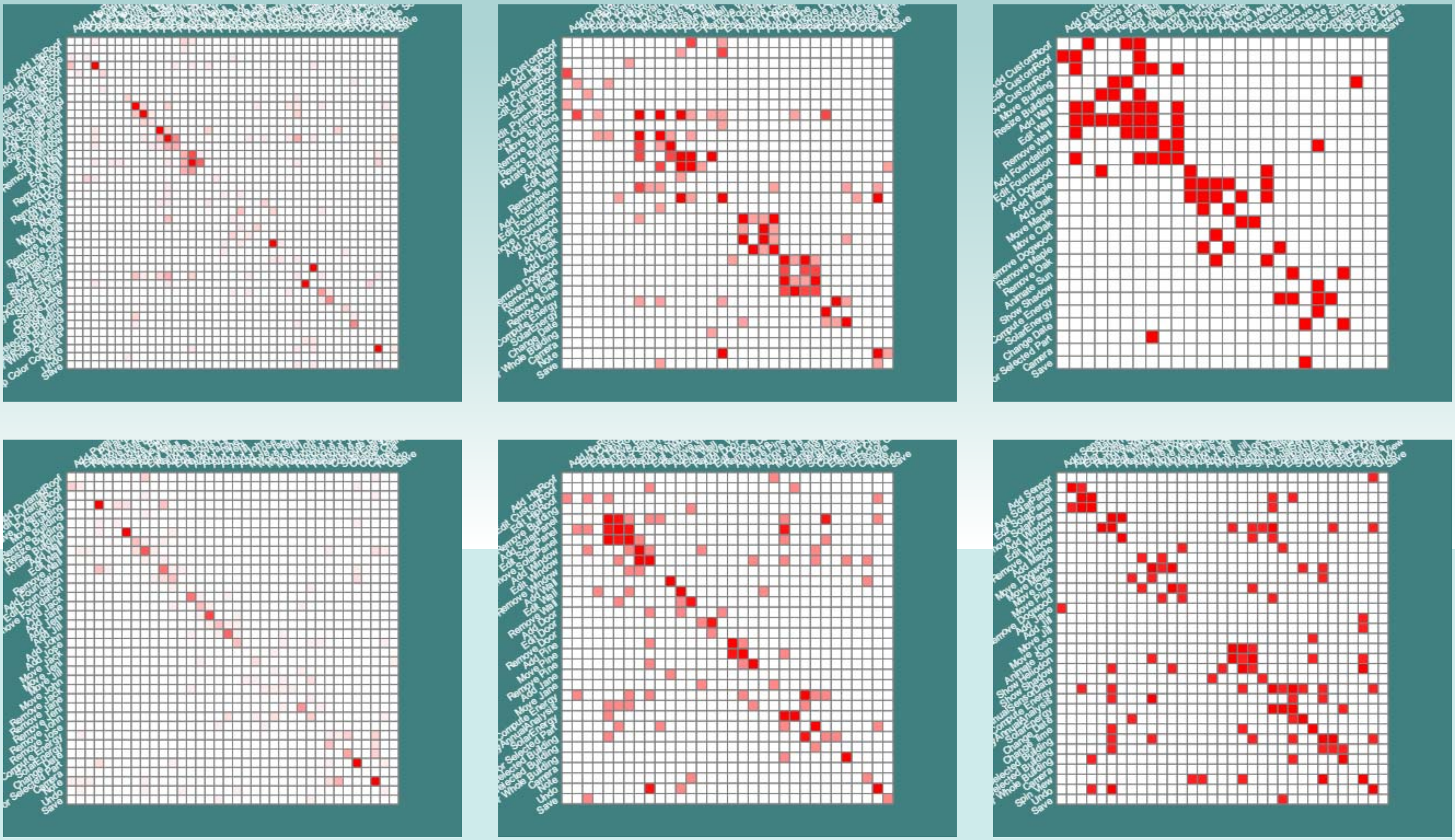
Construction (~200s), analysis (~450s)

$$(f \otimes g)(\tau) = \int_{-\infty}^{\infty} f^*(t) I(t+\tau)\, dt$$



VPA tool: Heat map of task transitions

Transitions from tasks to tasks may reflect how students use the CAD tool to solve a design challenge.



Few transitions

Localized transitions

Frequent transitions

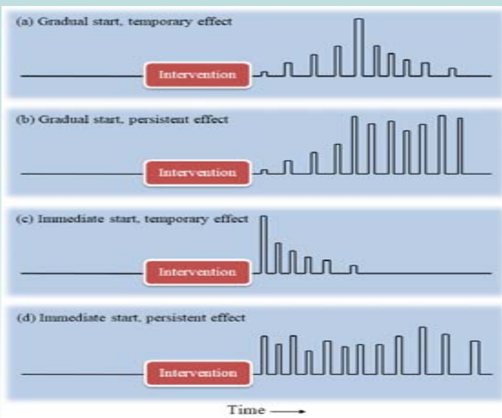
* This kind of heat map is a visual representation of the adjacency matrix of a design graph.

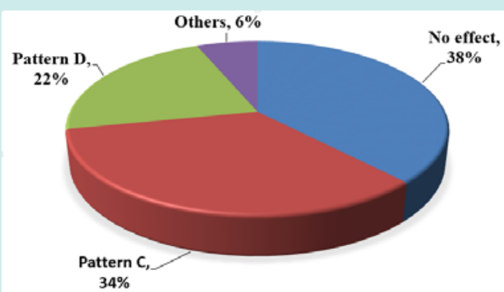
VPA tool: Response functions

How do students respond to an intervention?

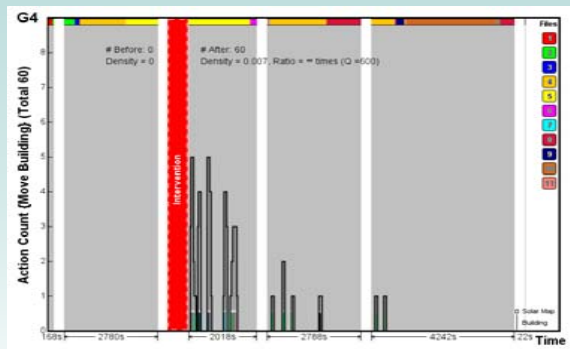
(An intervention can be computer-generated feedback, teacher instruction, or student discussion.)

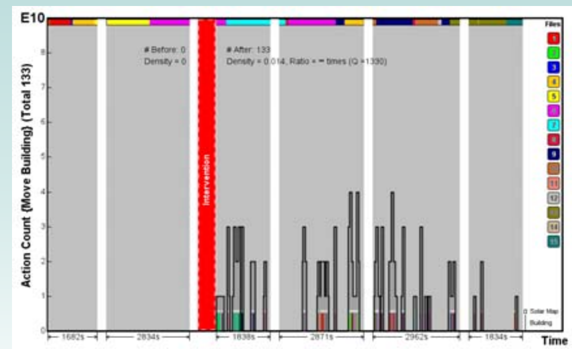
$$x(t) = \int_{-\infty}^{t} R_x(t-\tau) I(\tau) d\tau$$

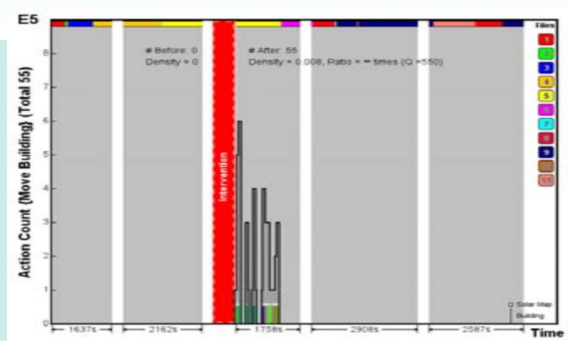


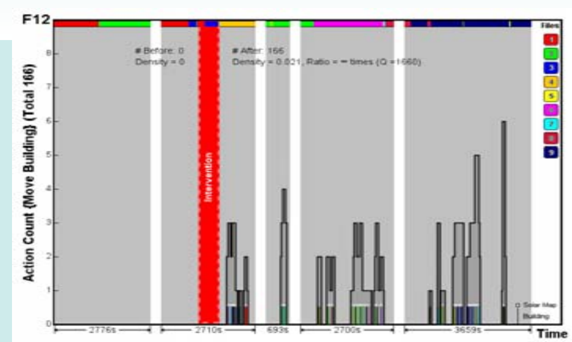


The distribution of response patterns of 65 students









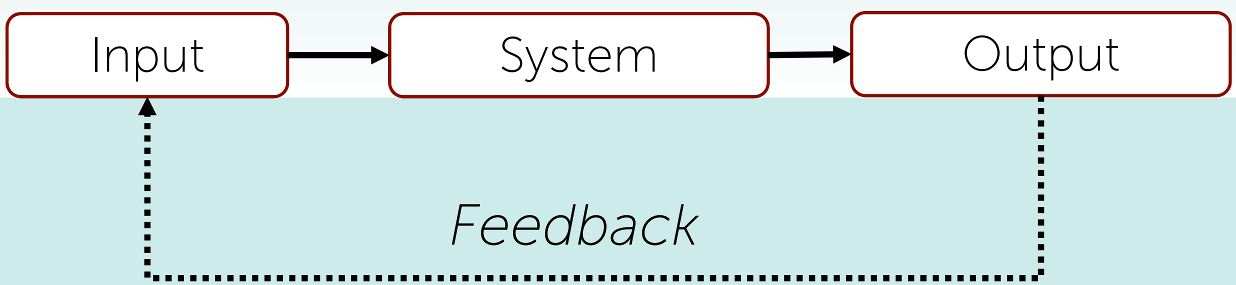
Pattern C: Decay

Pattern D: Persistent

Part III

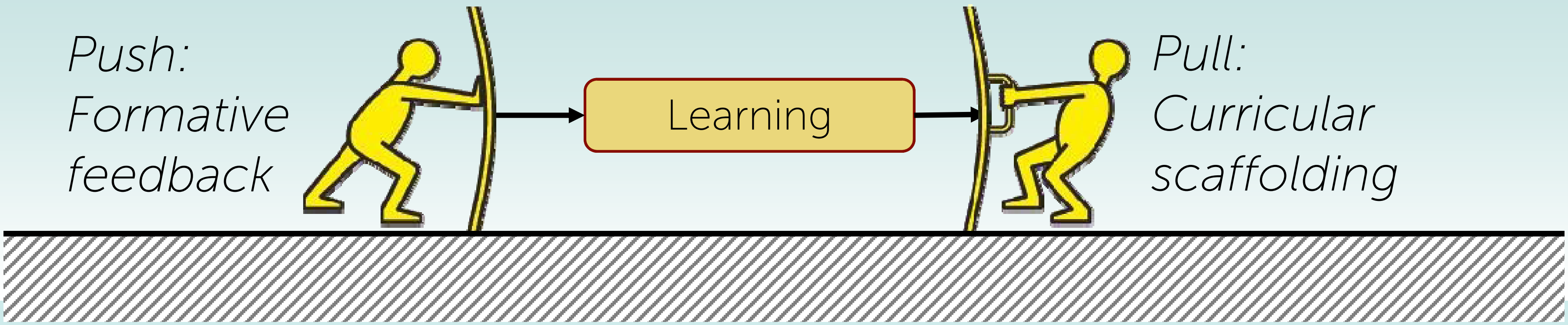
Develop Automatic Feedback

to Guide Student through Complex Engineering Design



The position of feedback in learning

SmartCAD is integrated with curriculum units that specify the design specifications and provide instructional scaffolding. Feedback provides an additional driving force for learning.



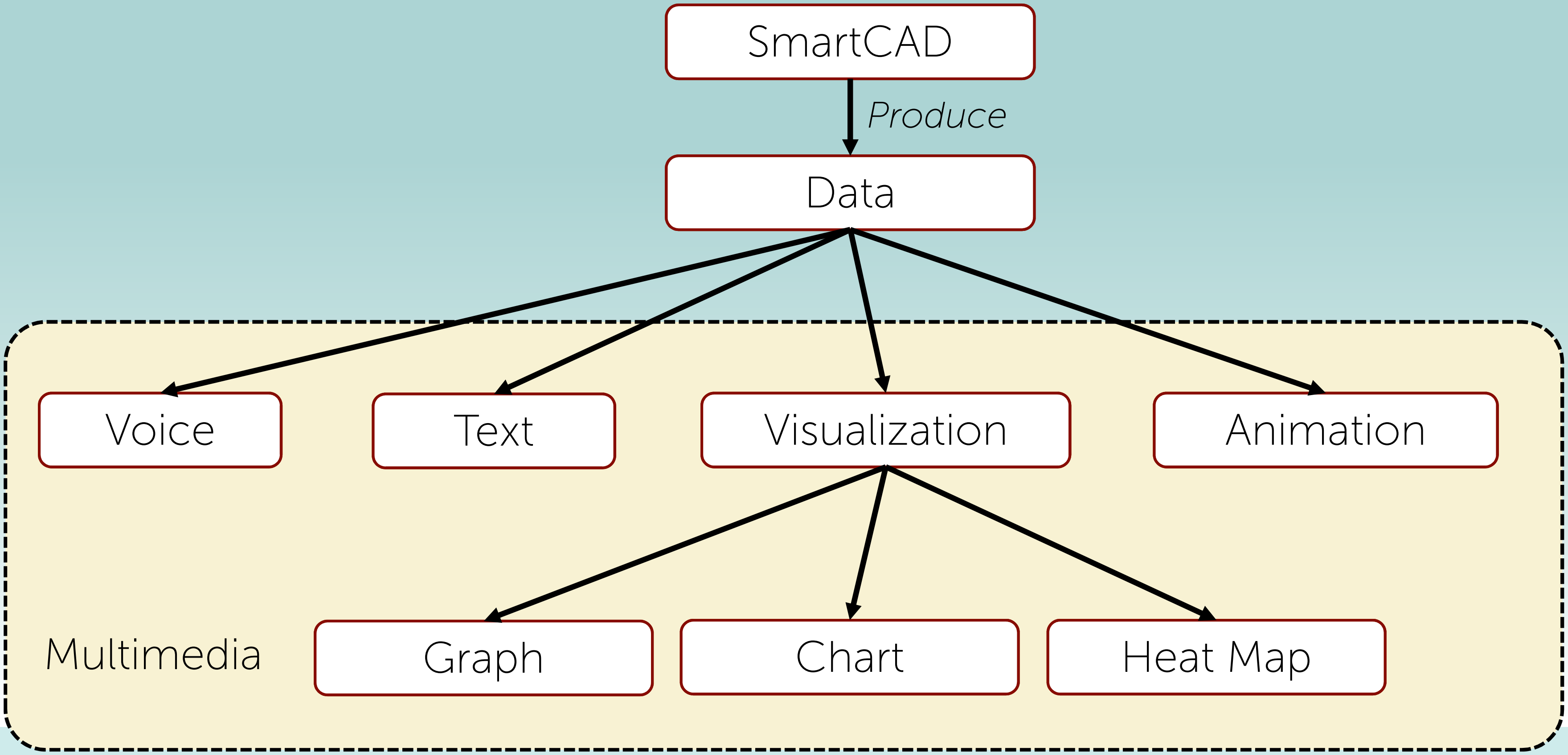
What are the differences between SmartCAD and conventional analysis in CAD?

Feedback is based on studying the designer, the design, and the CAD tool as a whole system (i.e., human is a variable in the system).

	Conventional CAD Analysis	SmartCAD Feedback
Subject of study	Product	Product + Designer
Engagement of user	Passive	Active
Criteria of success	Meeting design specs	Meeting design specs and learning STEM

Representations of feedback

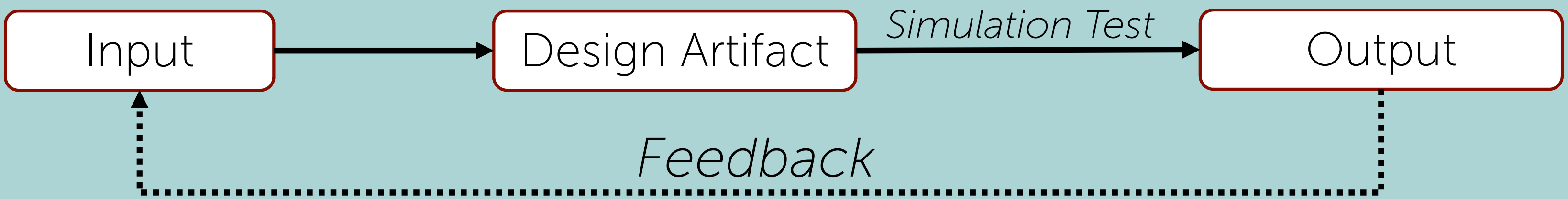
Feedback communicates suggestive multimedia to students



Definitive feedback: when the data suggests clear instruction
Interpretive feedback: when the data needs interpretation (e.g., reading a graph)

The system can't interpret the data if it is not "smart" enough or the data is too complex. One way to think about our research is to increase data mining capacity (e.g., feature extraction) so that feedback can be more definitive.

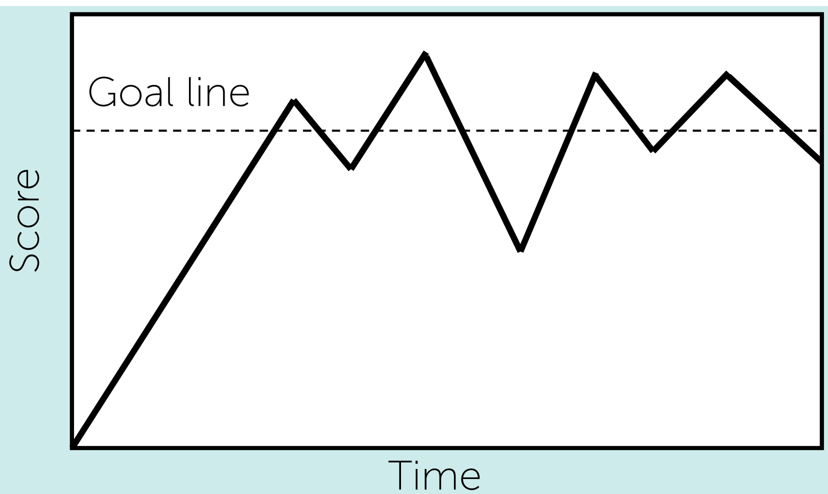
Feedback based on artifact mining

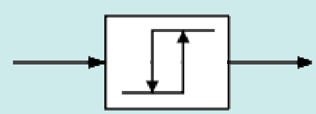


Goal-directed feedback

Goal types	Examples	Drivers
Explicitly bounded by specifications	Design a net-zero house that consumes less energy than it generates	Total net energy
	Design a house that costs no more than $200,000 to build	Total cost
Implicitly bounded by constraints	Design a solar park that generates as much electricity as possible	Total energy output
	Design a city block that has fair sunlight access for every building	Fairness score

An example feedback model for explicitly-bounded goals: Bang-bang control





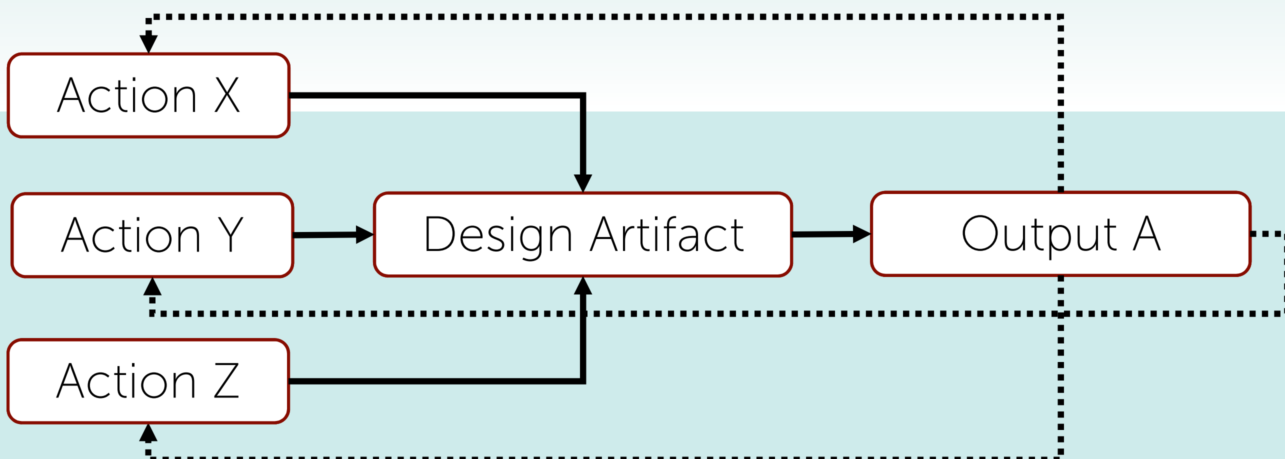
Score higher than goal line: OFF
Score lower than goal line: ON

Challenges in creating feedback in design

Feedback is meant to modify designer behavior, but what aspect of the behavior?
(Behavior is defined by a sequence of actions.)

Case I: Only one action occurs before testing the design, changing only one output

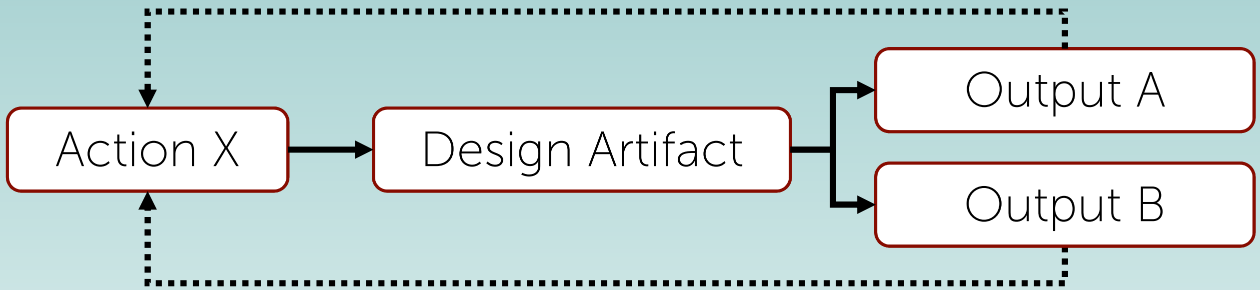
Case II: Multiple actions occur before testing the design, changing only one output



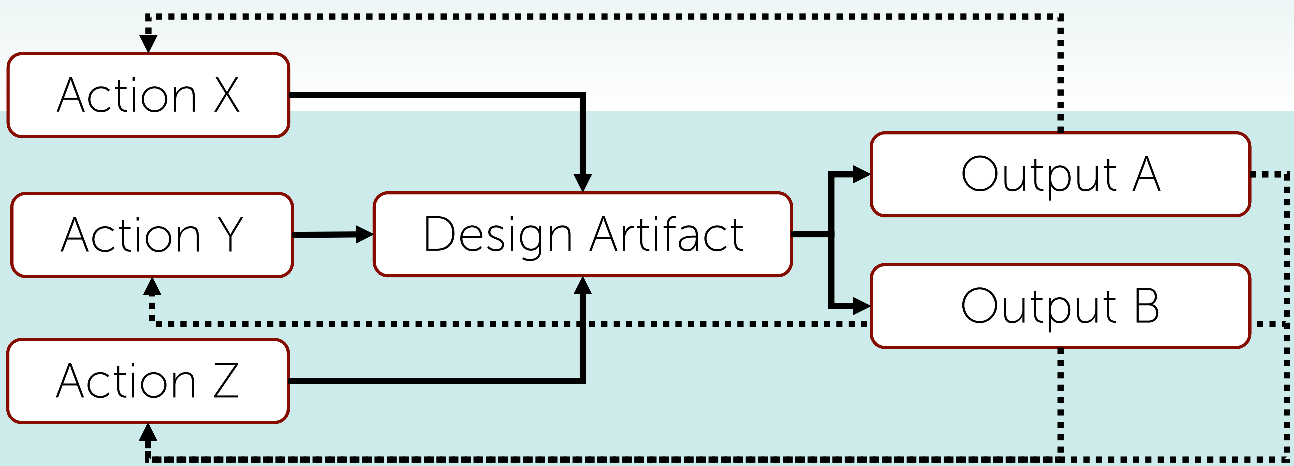
Challenges in creating feedback in design

How should SmartCAD respond to the user's actions?

Case III: Only one action occurs before testing the design, changing multiple outputs



Case IV: Multiple actions occur before testing the design, changing multiple outputs

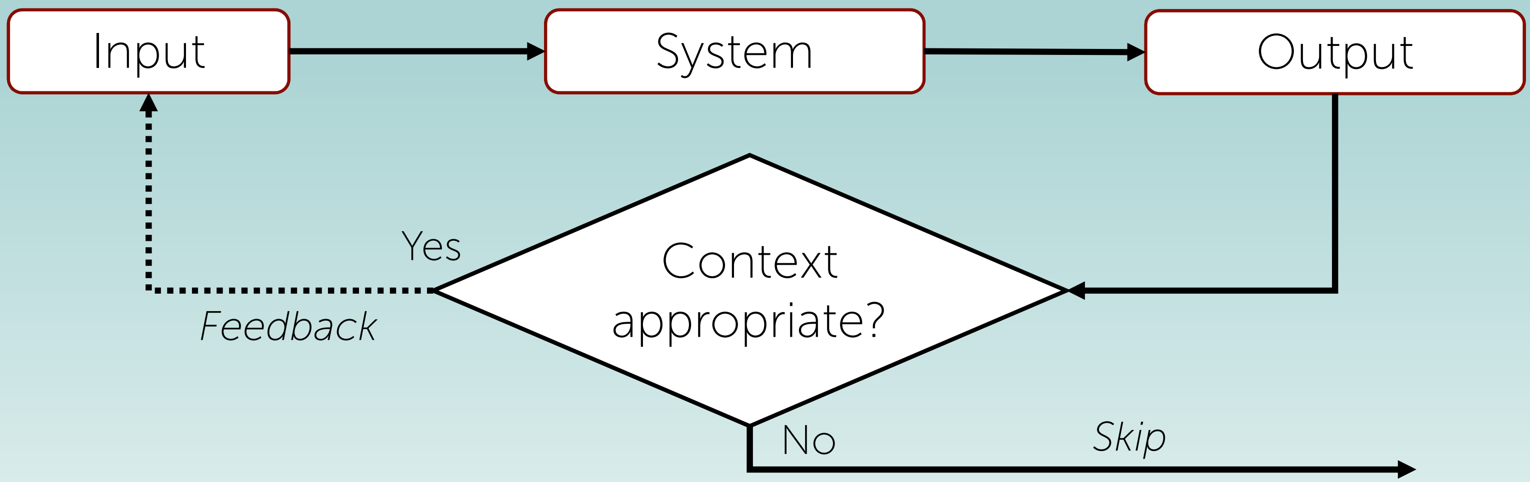


Feedback based on action mining

Types	Examples	Drivers
Action monitor	Detect whether action X has occurred. If X is required, feedback should instruct the designer to take action X.	Action counter
	Determine the effect of feedback by checking if an expected action has followed the instruction within a given period.	Action counter
Relation monitor	Actions $\{X_1, X_2, \ldots, X_n\}$ must all happen in order to solve a problem.	Correlation function
	Actions $\{X_1, X_2, \ldots, X_n\}$ must happen in a given sequence in order to solve a problem.	Sequence pattern

Context awareness

Determine the timing for giving feedback



Example of contexts

- If a building is still under construction, don't provide feedback to its performance.
- If the designer has been working on solar panels, provide feedback related to solar panels.

Thank you
for your time!