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Visual Process ANALYTICS

By Charles Xie

Analytics has never been more important to our economy than it is today. According to a 2014 article in Forbes, "Business analytics is now nearly a $16 billion business for IBM, on track to reach $20 billion in 2015." Business analytics research has produced technologies for transforming large quantities of data into meaningful information used for making business decisions or developing business strategies with an unprecedented speed and accuracy.

As learning software that can stealthily log everything students do becomes more popular, education will also become more data-driven. Just as instantaneous business data helps people stay in business, dynamic, fine-grained learning data may help teachers respond to students' needs more quickly and precisely. But this will not happen without investing in building the cyberinfrastructures, in particular the core engines of analytics that glean learning from data. While IBM's commitment to business analytics illuminates the possible future of education powered by learning analytics, the sheer scale of IBM's investment also suggests that such a vision requires tremendous efforts. To this end, the National Science Foundation has funded several projects at the Concord Consortium to conduct basic research in this field. This article introduces Visual Process Analytics (VPA), a data mining platform developed by some of those projects to support educational research and assessment based on analyzing and visualizing process data collected by sophisticated learning software.

"New technologies thus bring the potential of transforming education from a data-poor to a data-rich enterprise. Yet while an abundance of data is an advantage, it is not a solution. Data do not interpret themselves and are often confusing—but data can provide evidence for making sound decisions when thoughtfully analyzed."

—*Expanding Evidence Approaches for Learning in a Digital World, Office of Educational Technology,* U.S. Department of Education, 2013

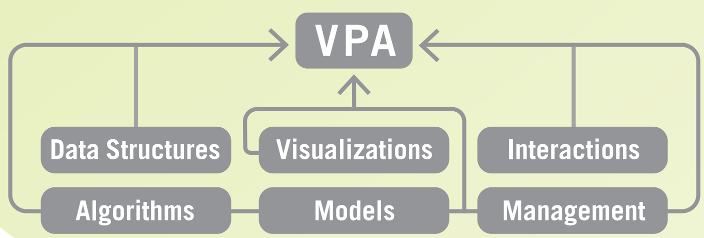


Figure 1. The six pillars of the VPA platform.

The DRIP Problem

One goal of VPA is to create a platform for tackling the DRIP ("data rich, information poor") problem, a central challenge in leveraging large amounts of computer-generated student data to improve education. The DRIP problem worsens when learning becomes more open-ended because: 1) the supporting software can generate more types of data as students explore more variables, 2) wider and deeper exploration can take more time and, therefore, produce more process data, and 3) indicators of unbounded learning are more complex to define and more difficult to find.

Open-ended inquiry and design activities are key to learning the science and engineering practices promoted by the Next Generation Science Standards. Students' "microscopic" action data logged by the supporting software during these activities, however, often appear to be so noisy that finding any order in them becomes a daunting task. Without tools that can reveal patterns in the data, researchers and teachers get nothing but a DRIP problem.

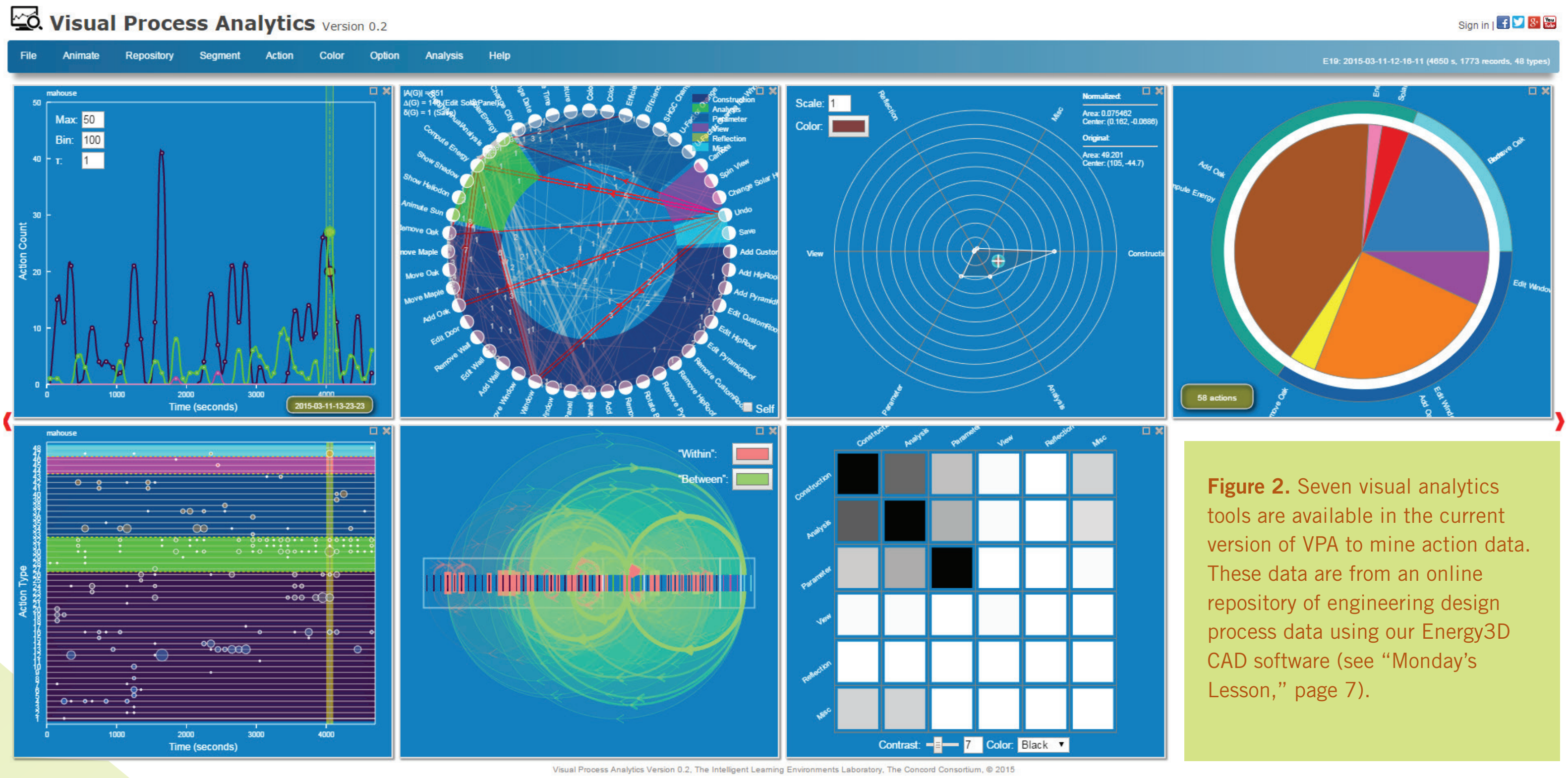


Figure 2. Seven visual analytics tools are available in the current version of VPA to mine action data. These data are from an online repository of engineering design process data using our Energy3D CAD software (see "Monday's Lesson," page 7).

The Visual Process Analytics Platform

Our ultimate goal is to equip teachers with informatics and infographics for monitoring student progress and assessing their learning anywhere, anytime. For this purpose, we created VPA as a Web app that teachers can access from any device. VPA can load a data set from an online repository or from a hard drive. Although it currently serves only our own data repositories with student data from engineering design and mixed-reality activities, VPA is intended to be a generic platform for process mining and visualization. VPA is able to recognize a JSON data set that encodes student activities, provided that the data set is formatted as a stream of timestamped JSON objects and a schema that defines the tags and attributes of the objects is given to configure it.

Like business analysts who use online analytical processing (OLAP) tools to analyze multidimensional data interactively from multiple perspectives, educators can use VPA in similar ways: 1) *roll-up* allows users to aggregate and analyze learner data in different dimensions, 2) *drill-down* allows users to zoom into and navigate through the details, and 3) *slicing* and *dicing* allows users to extract a subset of data and visualize it differently.

In addition to the OLAP features, the VPA platform is supported by six pillars (Figure 1)—software modules that perform various kinds of visualization, analysis, and management of data. Interactive visualizations are fundamentally important to VPA because 1) a picture is worth a thousand words, 2) humans are often more capable than computers of recognizing complex patterns in pictures, and 3) interactive graphics provide more dimensions for exploring data than static graphics.

Under the Hood

Data Structures

Since real learner data are often multi-faceted, data fed to VPA are first sifted into different types of data structures, each representing a different mathematical view of the data. For instance, a sequence of action data can be stored and treated as a time series (an array of numeric data collected over time) that describes when different types of actions occurred with what results on which objects, or as a directed graph (a network of nodes linked by arrows) that describes the transitions among different actions and tasks. Each type leads to a different way to think about the data, enabling various visualization and analysis methods to be developed.

Visualizations

Scientific visualizations are powerful because they help people make sense of data by rendering salient, intuitive pictures of the data being examined. The multi-faceted nature of data suggests that a single type of visualization may not suffice to represent a data set. This is why VPA provides multiple visualizations to create a more holistic view. Seven types of visualizations—time series, directed graph, radar chart, pie chart, scatter plot, linkograph, and heat map (Figure 2)—are currently available, each depicting a unique aspect of a data set. Interactive and customizable, they allow users to examine data more flexibly. Each type also provides several options. For example, a time series can display as a histogram, a curve, a correlogram, a periodogram, a recurrence plot, and more (Figure 3).

Interactions

Like other visual analytics software, VPA provides a rich, interactive user interface for analyzing and viewing data. The graphical user interface for each visualization tool is dynamically generated based on the chosen settings. For example, to capture overall patterns in a time series, users can increase the width of the time bin to smooth the time series curve as necessary. Throughout VPA, tool tips with more information about the data pop up when users mouse over hot spots of the visualizations. Users can even take advantage of the temporal nature of the data to animate a visualization to further enhance the visual effects.

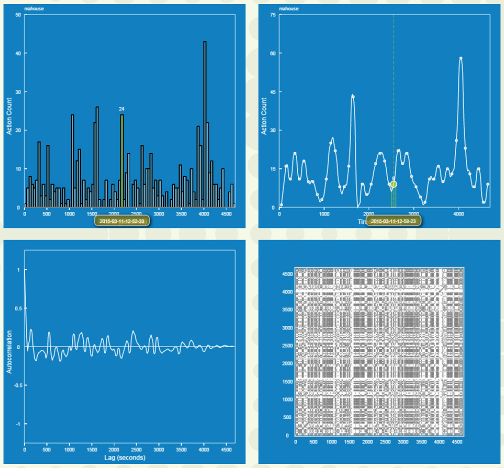
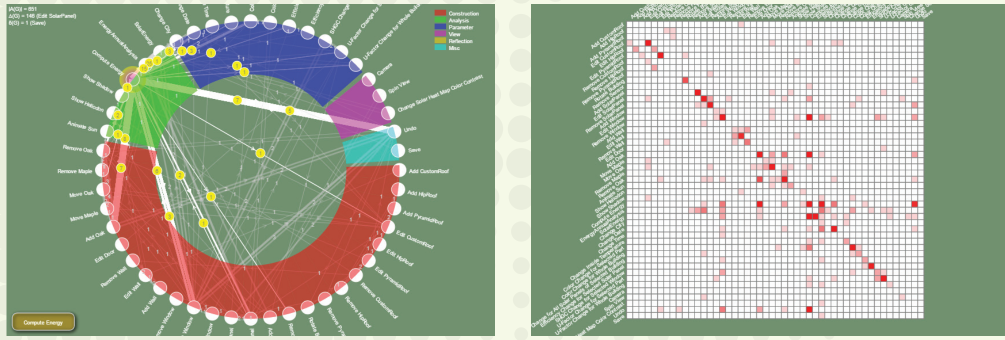


Figure 3. Four different visualizations of a time series in VPA. Clockwise from the top left: histogram, curve, recurrent plot, and correlogram.



(a) (b)

Figure 4. (a) With the built-in interactivity in VPA for directed graphs, users can look at the transitions among actions within a selected time interval or the actions linked to a selected type over the whole period. (b) VPA shows the adjacency matrix of a directed graph as a heat map that visualizes the distribution of transitions in the action space. The more intense colors of the diagonal elements indicate that this student tended to take some types of action continuously during this time period.

Algorithms

By manipulating the visualizations, users develop basic ideas about the data. But they need deeper analyses to reveal hidden patterns. VPA provides a growing set of algorithms for in-depth analyses. For instance, VPA employs time series analysis when the data are viewed as time series and graph theory when the data are viewed as graphs. Autocorrelation and cross-correlation functions in time series analysis can be used to search for patterns of iteration, correlation, or causality. These algorithms work as if we print two time series on transparency films, overlay them, and then manually slide them horizontally to search for similarities or correlations. Within the framework of graph theory, on the other hand, any process of interacting with software can be viewed as a directed graph that connects all actions with arrows that represent transitions (Figure 4a). Once the process data are coded in this way, VPA computes its properties and visualizes its adjacency matrix with a heat map that makes the high-frequency transitions clear (Figure 4b).

Models

One of our research goals is to model complex cognitive and learning processes so that we can describe, classify, or even predict student behaviors. For this purpose, we include tools for fitting the data with statistical models. For example, the autoregressive integrated moving average (ARIMA) model in time series analysis may be used as a general model to probe the degree to which a student's action was influenced by previous actions. The results can be used to gauge how autoregressive or iterative the process was.

Management

VPA includes many features designed to facilitate data mining, including:

- **Browsing.** VPA is a data browser—users can browse a data repository using arrow buttons or jump to a data set using drop-down menus for selecting classes, students, and segments. Every time a new data set is loaded, VPA automatically updates all the visualizations on the screen.
- **Persistence.** A state of data mining in VPA is called a *perspective*. Users can save perspectives as files to keep track of their work, compare multiple views, document a finding, or continue the analysis later. In addition, VPA remembers the last perspective—when users return, VPA comes back to the exact point of analysis where they left.
- **Output.** VPA results can be exported as data or image files that can be further analyzed or displayed using other programs.

The Future

Launched only a few months ago, VPA is in its infancy. Its current form is more suited for researchers than for teachers. But we hope to develop a recommendation engine that digests low-level data and outputs high-level information to teachers through a series of dimensionality reduction. We envision a future in which every classroom is powered by more advanced VPA-like informatics and infographics systems that support day-to-day teaching and learning using a highly responsive evidence-based approach. At a time when business runs on analytics rather than opinions, it is not fair that teachers have to rely on simple hunches or scarce information about their students' learning processes to teach. The research that we are undertaking is paving the way to a future in which teachers are empowered with tools on par with business analytics.

LINKS

Visual Process Analytics
http://vpa.concord.org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ARE THE CREATORS OF Energy3D.

Monday's Lesson:

Designing an Energy-Plus Home

By Charles Xie and Saeid Nourian

Are you looking for high school engineering design projects that meet the requirements of the Next Generation Science Standards (NGSS)? Do you need free, high-quality software and curriculum that engage students in solving complex real-world problems like scientists and engineers and yet can be easily implemented? Do you want students to be more technically prepared to tackle energy and environmental issues in the future? If you answered "yes" to these questions, this lesson is for you.

Energy3D is a simplified CAD program for designing buildings and communities that take advantage of renewable energy sources such as solar and geothermal energy to reduce fossil fuel use. Based on weather data of more than 200 worldwide locations, Energy3D allows students around the world to design sustainable architectural and solar solutions for their climates.

Unlike other CAD tools, Energy3D aims to engage students in science and engineering practices as required by NGSS. The integrated capability of concurrent design, simulation, and analysis within Energy3D enables students to test and evaluate multiple design ideas through rapid virtual experimentation.

The Energy-Plus Home Design Challenge

Challenge your students to use Energy3D to design an energy-efficient house that, over the course of a year, produces more renewable energy than the energy required for heating and cooling it. In addition to this goal, students must also meet a set of design criteria and constraints. For example, the house should have one of three specified architectural styles, the size cannot be too big or too small, and the cost must not exceed the budget.

Energy3D's easy-to-use interface allows students to quickly sketch up realistic-looking houses using a basic set of design elements, including walls, roofs, windows, solar panels, and trees (Figure 1). Students can adjust the properties of each element such as size, location, orientation, U-value, solar heat gain coefficient, heat capacity, color, and more. Whenever they want to evaluate the effect of a change on the energy performance of the house under design, they can run the built-in thermal and solar simulators to generate a graph that itemizes and summarizes daily or annual energy use (Figure 2).

This design project meets the NGSS engineering standards in several ways: 1) it is a direct response to HS-ETS1-4 that requires students to use a computer simulation to model and solve real-world problems, 2) it promotes systems thinking as students can explore how individual elements collectively contribute to the overall performance of a house, and 3) it creates many opportunities for learning about trade-offs and optimizations as the built-in simulators greatly accelerate the feedback loop necessary for iterations.

Although the engineering projects based on Energy3D are limited to virtual design, they have distinct advantages: 1) students should have the opportunity to learn CAD as nearly every engineer today uses CAD, 2) software can simulate situations that are not possible to create in a school lab (e.g., waiting for a year to determine the annual energy use of a real house), and 3) the cost of implementing these projects is minimal—you only need computers that can run the free Energy3D software.

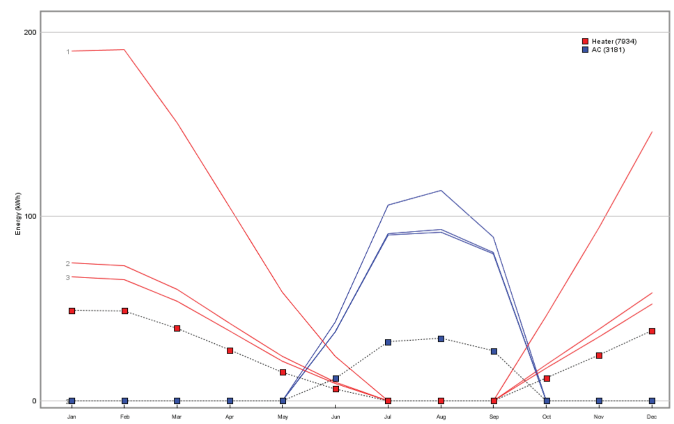

Figure 2. Energy analysis: The graph of monthly energy use (heating in red, cooling in blue) shows gradual energy savings through four improvements.

Figure 1. Solar analysis: The total solar radiation on a house in Boston on May 1 is visualized as a 3D heat map that reveals complex interplays among individual elements of a house and its surroundings.

LINKS

Energy3D
http://concord.org/energy3d

Energy-Plus Home Design Challenge
http://energy.concord.org/energy3d/projects.html