

Temporal Visual Analytics for Additive Manufacturing

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<http://csteed.com>

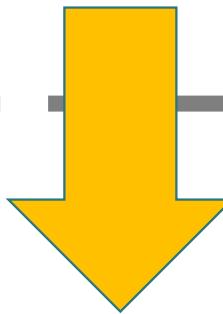
Computer Science and Mathematics Division

Oak Ridge National Laboratory

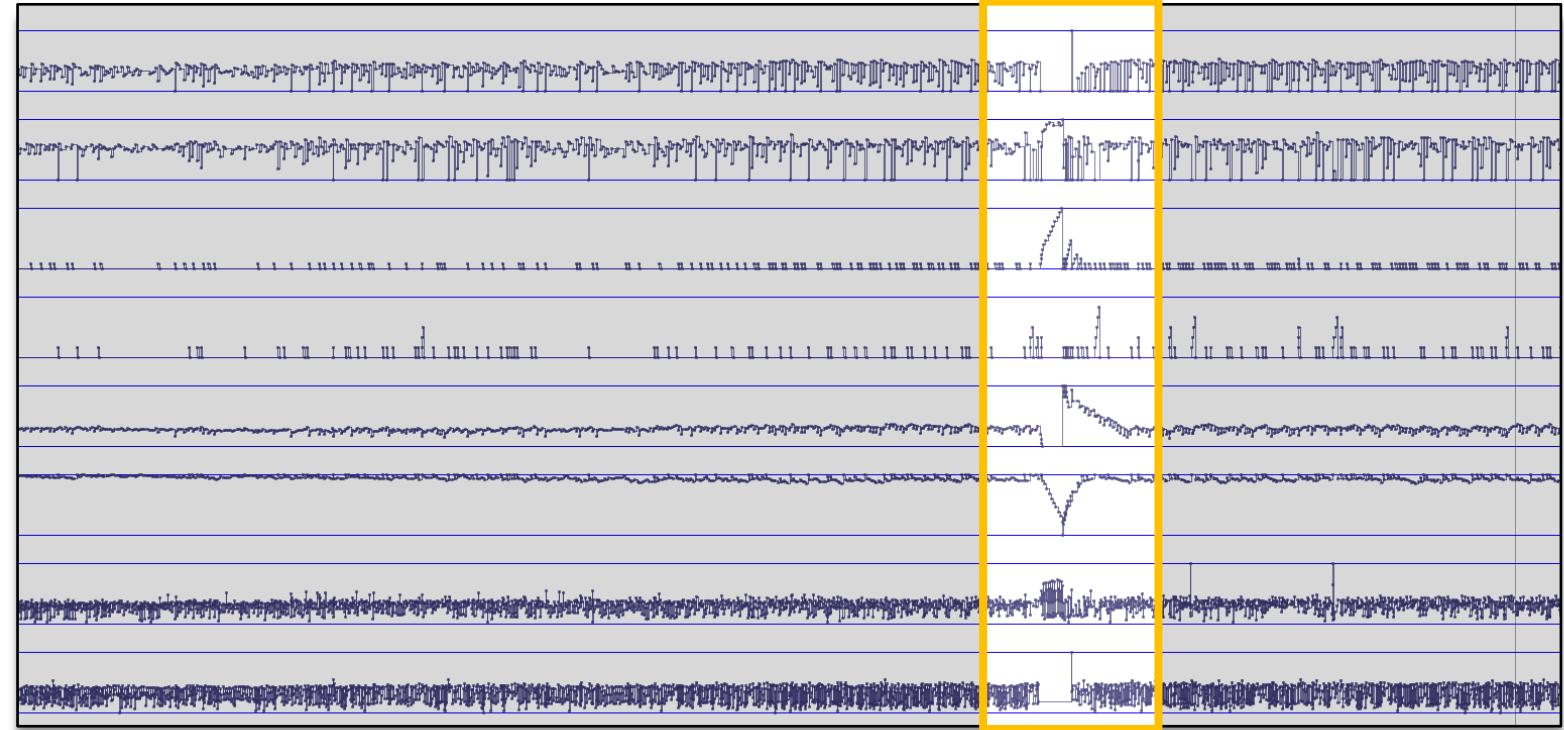
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DATA

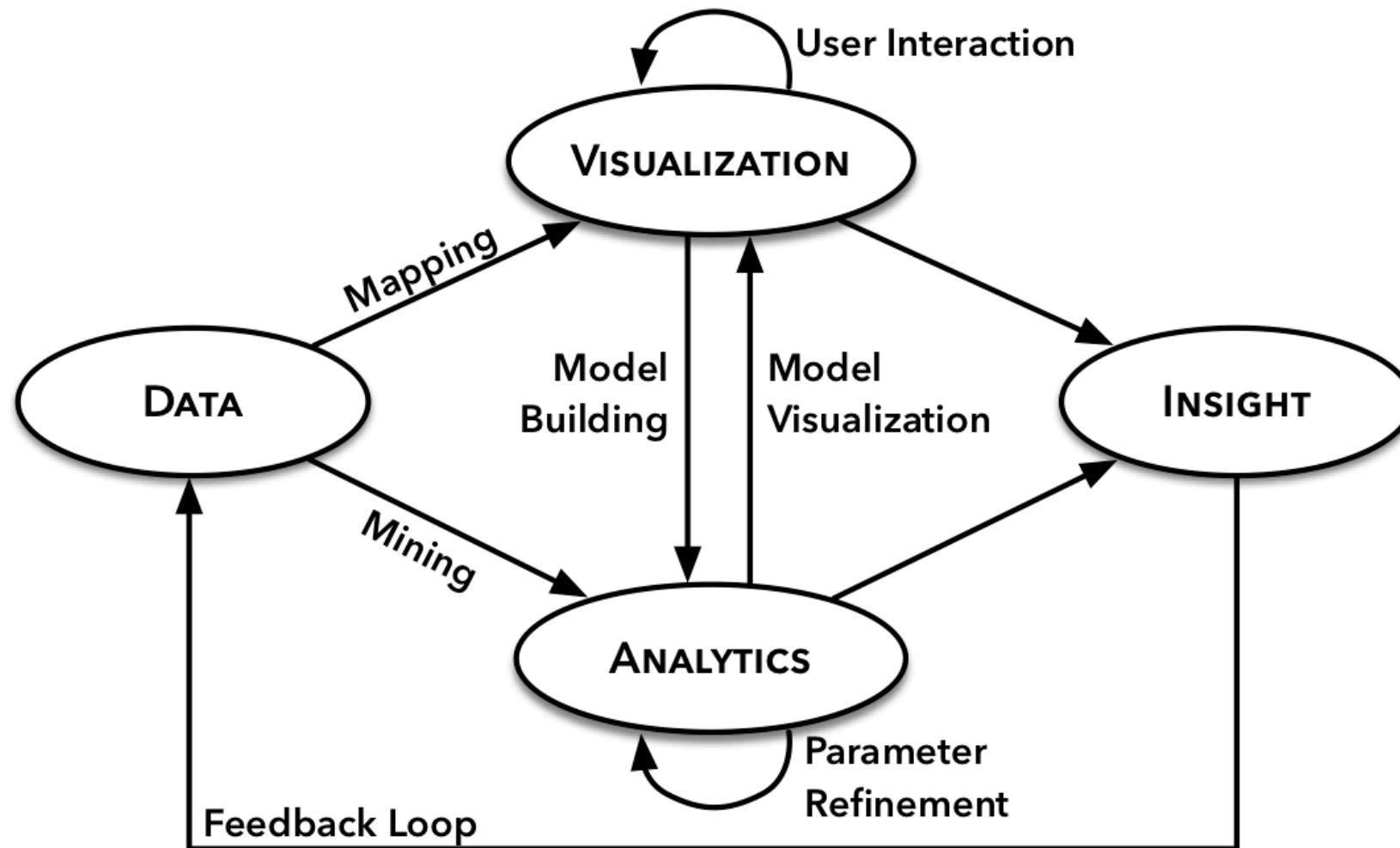


Insight



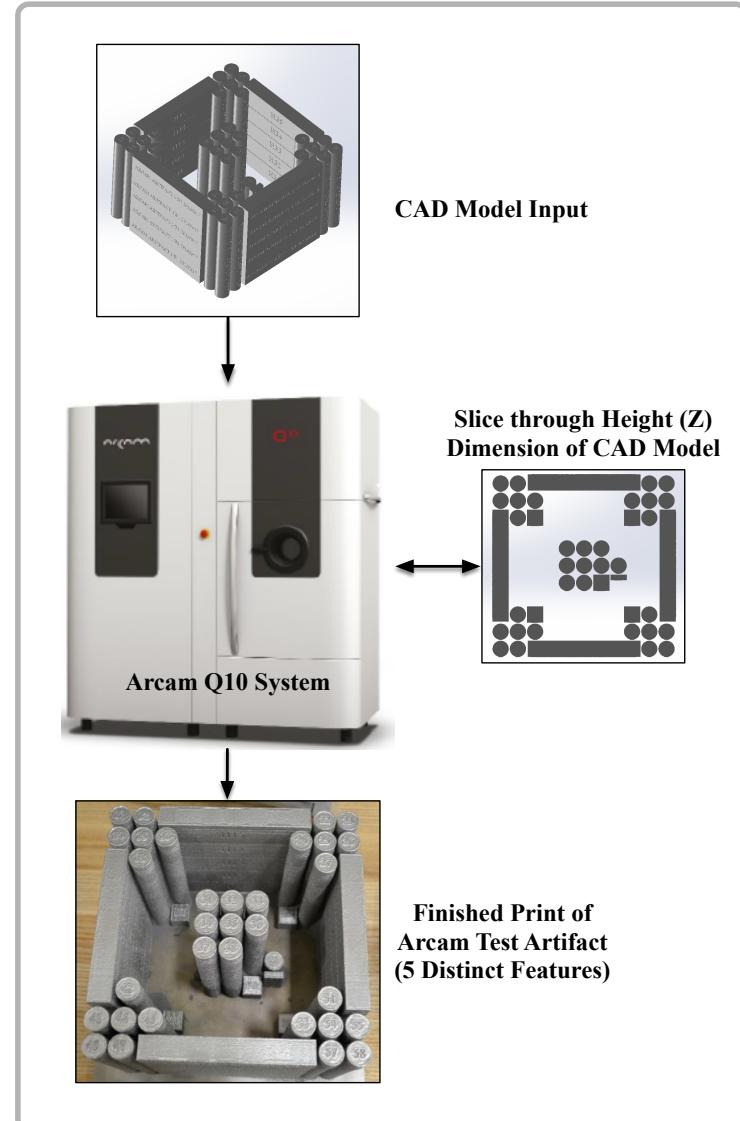
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492259	2016-06-17 21:07:03.466 OPC.Temperature.BottomTemperatureValidation SuperUser (OPC) 9526586 618.1999999999982
492260	2016-06-17 21:07:03.486 Process.CathodeTuningControl.CathodePower [OnChange(OPC.PowerSupply.Filament.VoltageFB)] Arcam.EBMControl.Process.CathodeTuningControl.OnCathodPowerChange() (Logic) 9526586 5.929202
492261	2016-06-17 21:07:03.516 Process.CathodeTuningControl.MeanCathodePower [OnChange(Process.CathodeTuningControl.CathodePower)] Arcam.EBMControl.Process.CathodeTuningControl.MeasureMeanPower() (Logic) 9526587 5.905572
492262	2016-06-17 21:07:03.516 OPC.PowerSupply.HighVoltage.SafetySignal [OnPositiveFlank(SafetySignalTimer.Timeout)] Arcam.EBMControl.Process.HighVoltageControl.OnTimeToSendSafetySignal() (Logic) 9526587 True

Visual Analytics: Uniting Humans and Computational Strengths

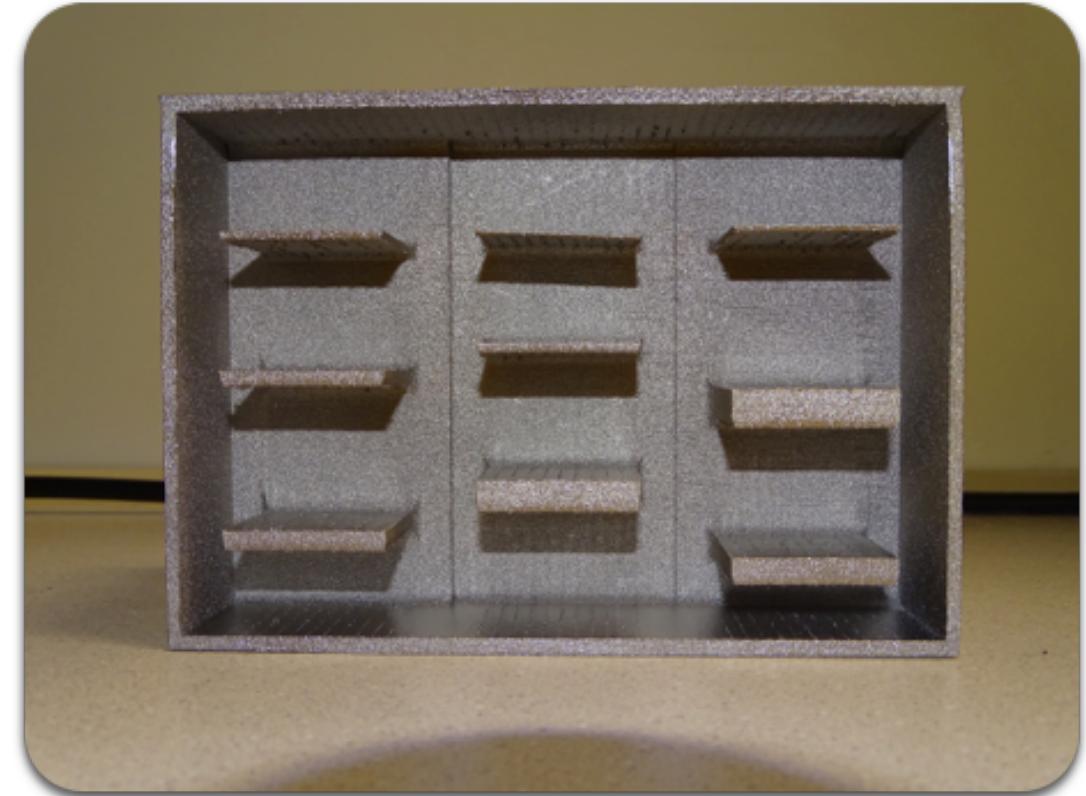
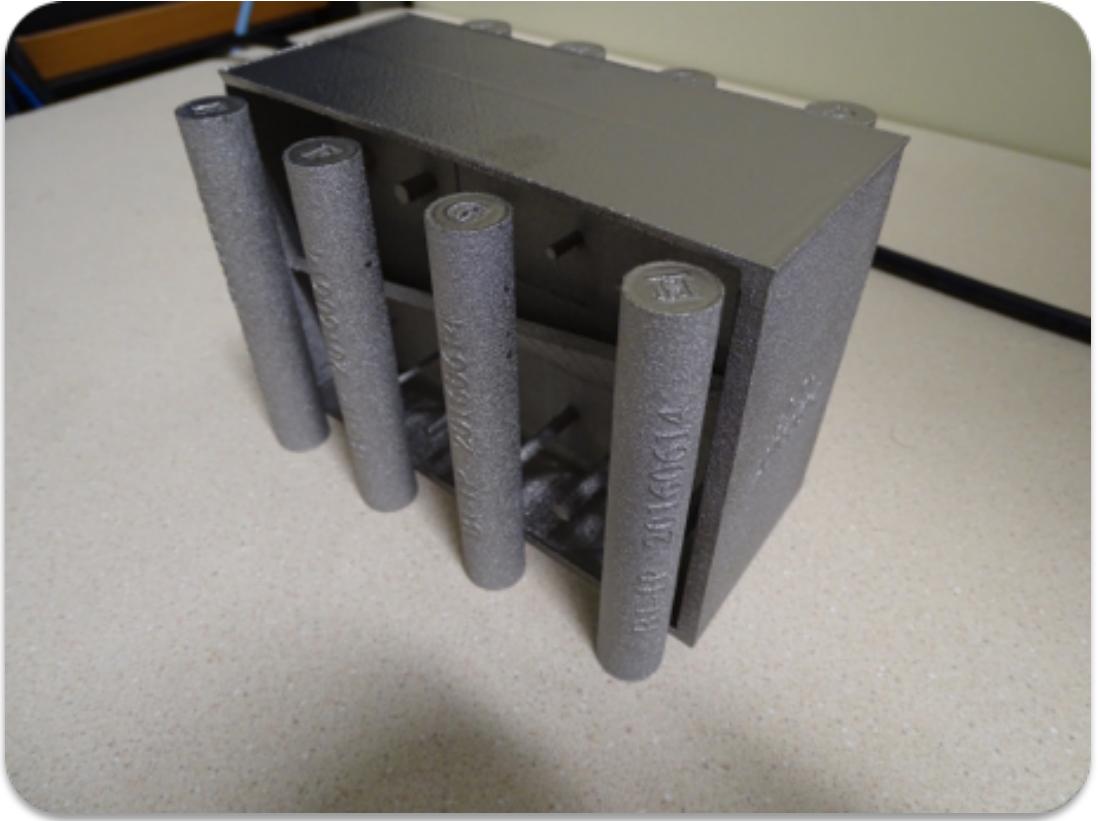


Additive Manufacturing

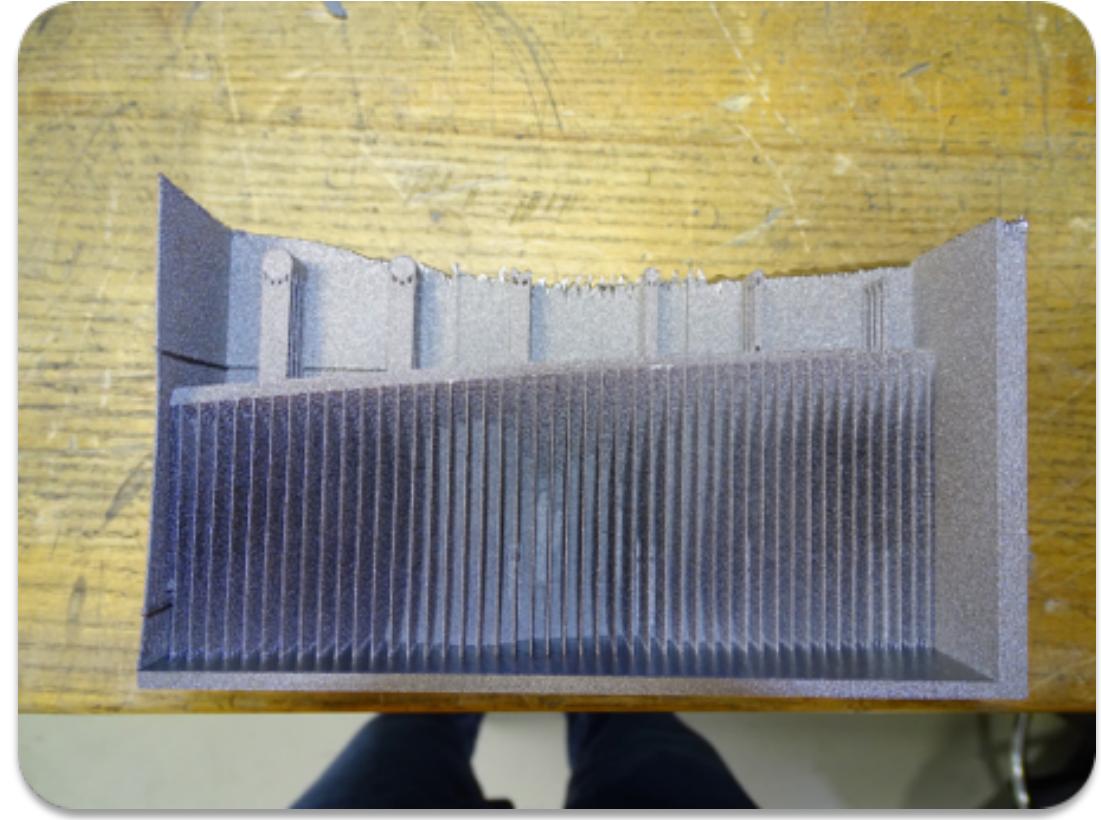
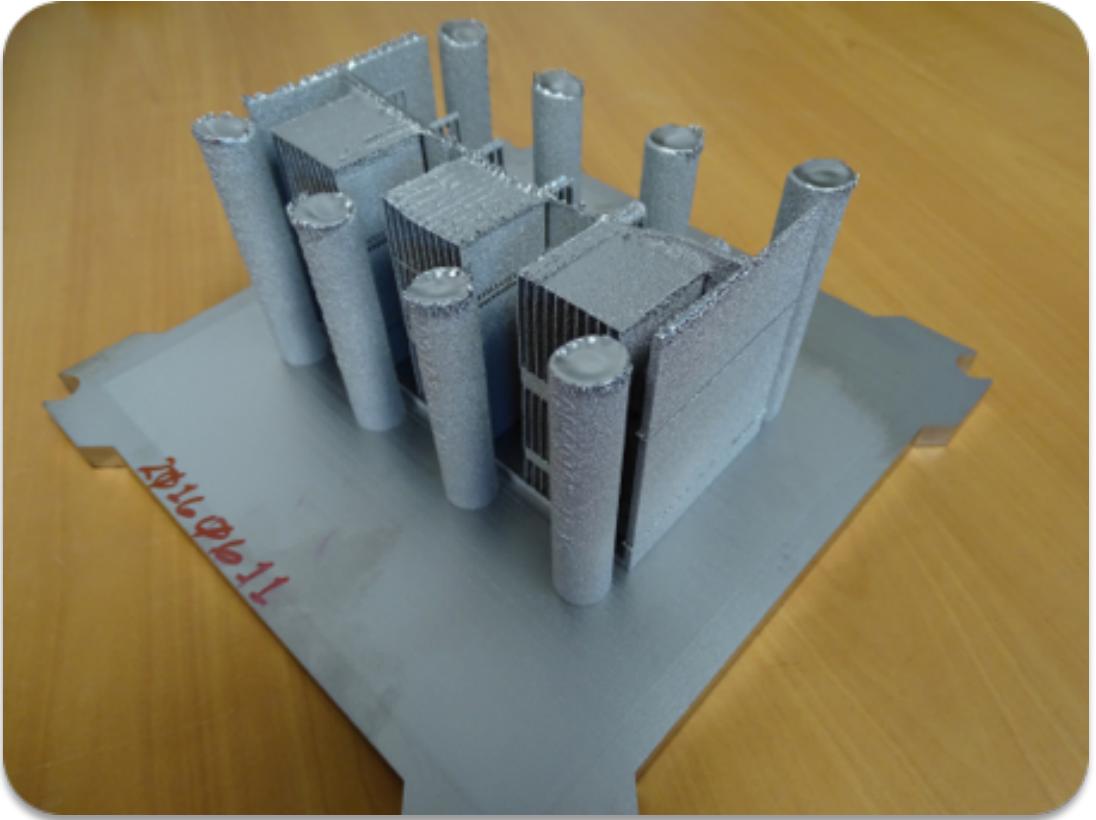
- Transformation of the manufacturing process
 - Greater geometrical freedom
 - Less material waste
- Need to certify quality of 3D printed objects to unlock the full potential
 - Requires a deep understanding of the log and imagery data from printer builds
- Excellent scenario for visual analytics tools



Examples of 3D Printed Objects (The Good)



Examples of 3D Printed Objects (The Bad)



3D Printer Log and Imagery Data

- Log files are integral to understanding the process, but challenging:
 - Long builds (hours)
 - Large (millions of readings)
 - Multivariate (thousands)
 - Irregularly sampled
 - Semi-structured text format
 - Multi-modal (imagery data)
 - Off the shelf tools are inadequate

Participatory Design of a New Visual Analytics Tool

Domain Experts

Dr. Ryan Dehoff

Additive Manufacturing



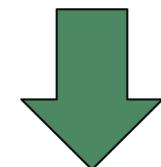
Scientific Domains

Large-scale 3D Printing



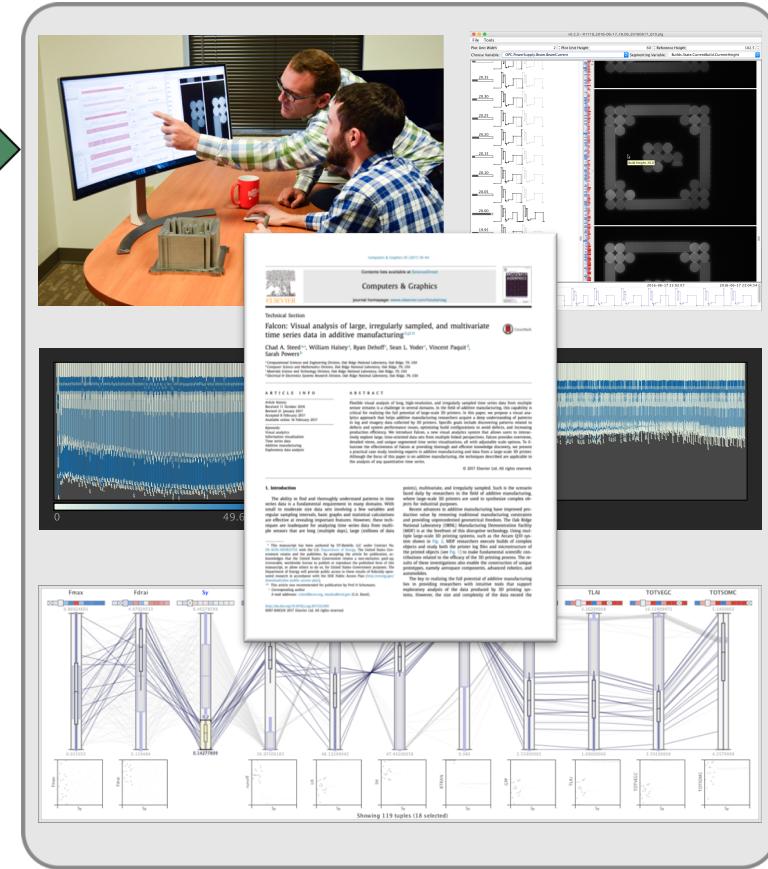
Real-world Data

Large, Complex, Unique



Results / Artifacts

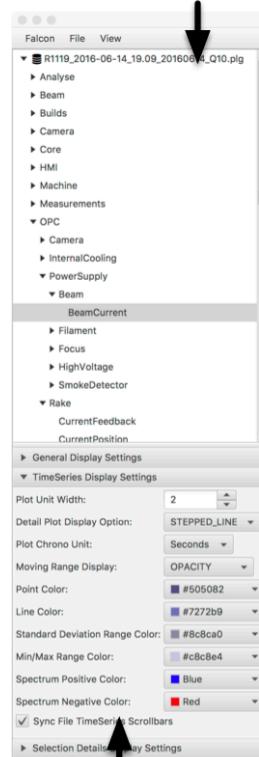
Tools, Techniques, Publications, Patents, Open Source Software



Introducing Falcon

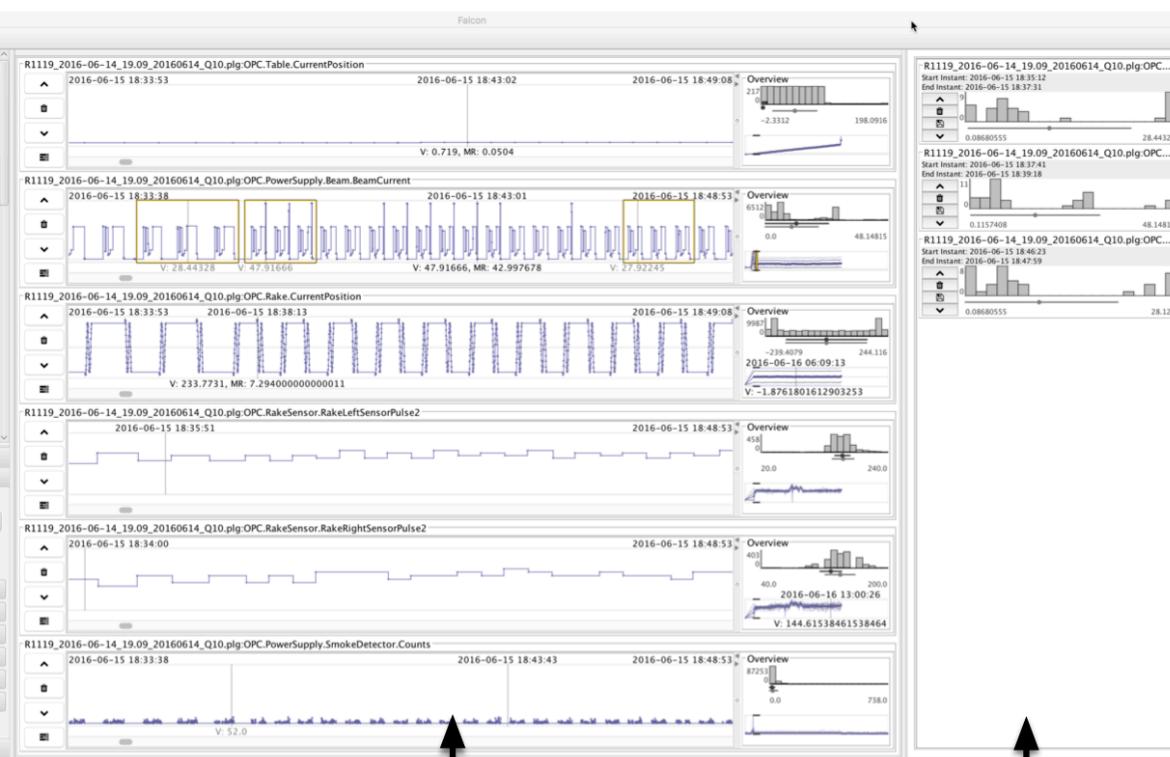
Main Analysis Window

File / Variables Tree View



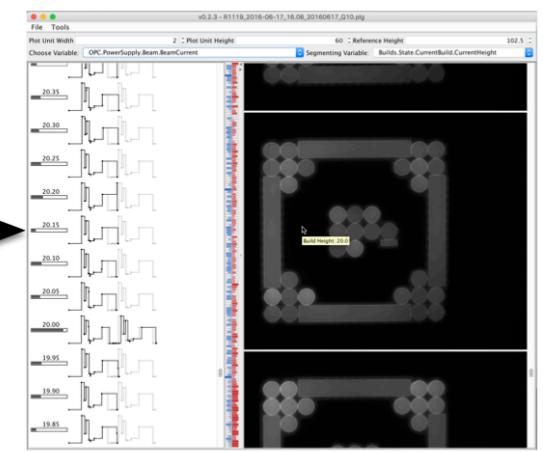
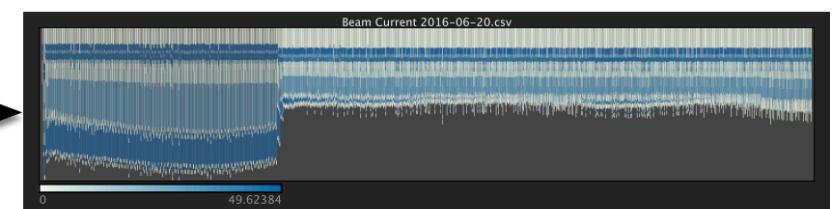
Settings Panel

Variable Visualization Panel
(Left: detailed time series, Right: overview)



Selection Details Panel

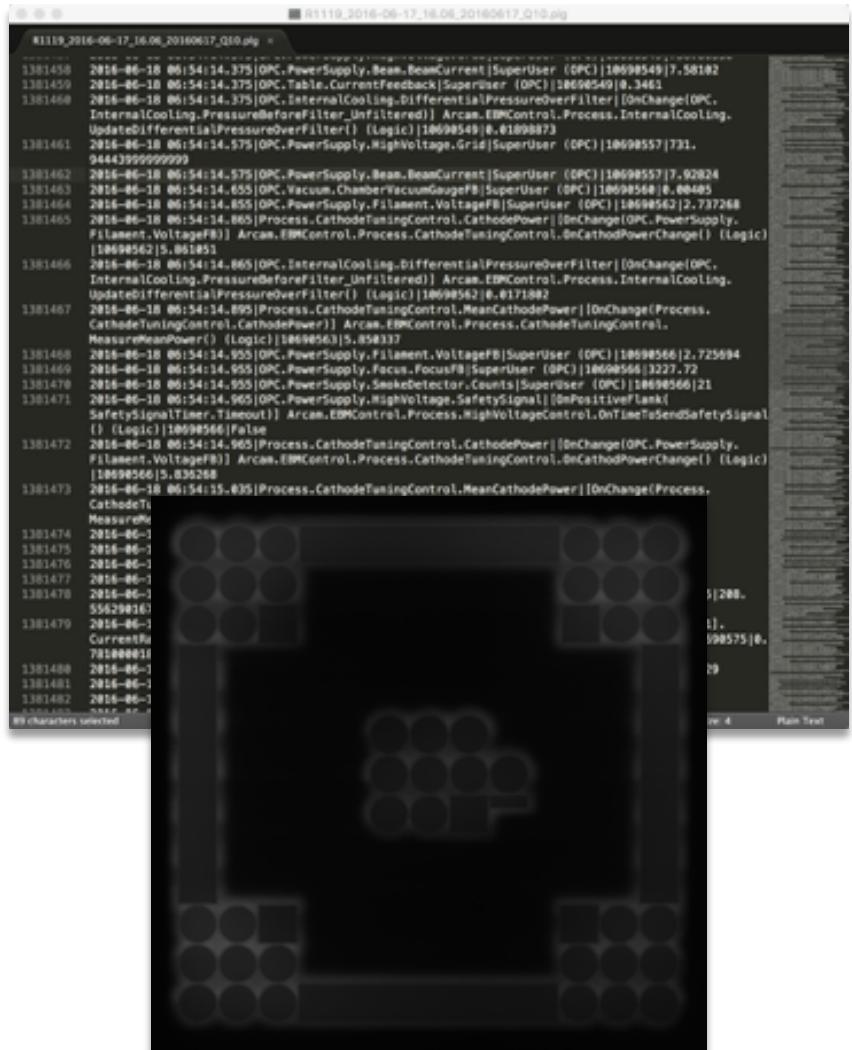
Waterfall Visualization



Segmented Time Series Visualization

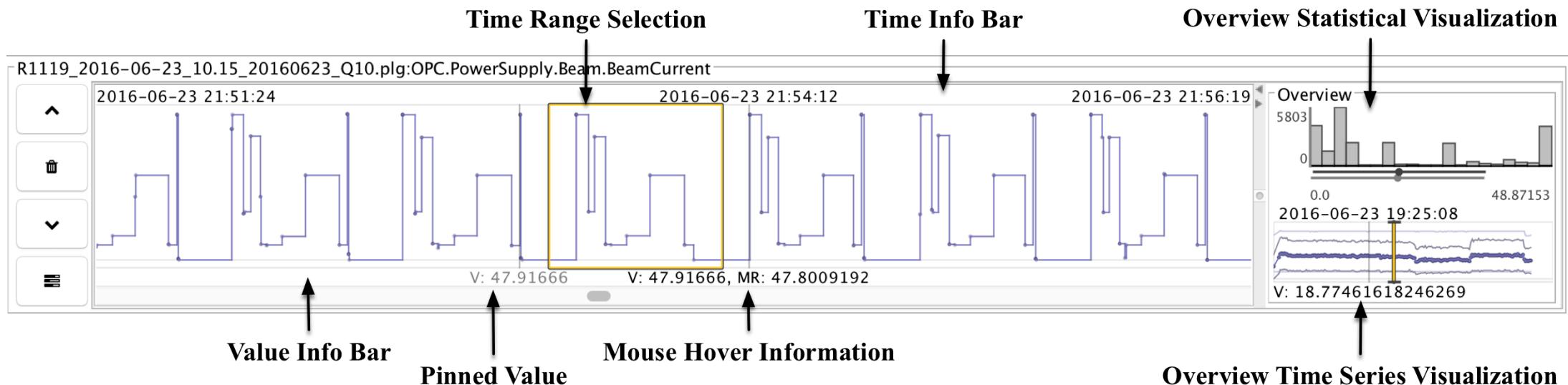
Data Transformation and Modeling

- Log files are read into time-based bins at variable levels of detail
 - Support drill down / roll up between overviews and detailed visualizations
 - Statistical summaries derived from raw data
 - Only read variable data into memory if requested
 - CSV import or custom reader available

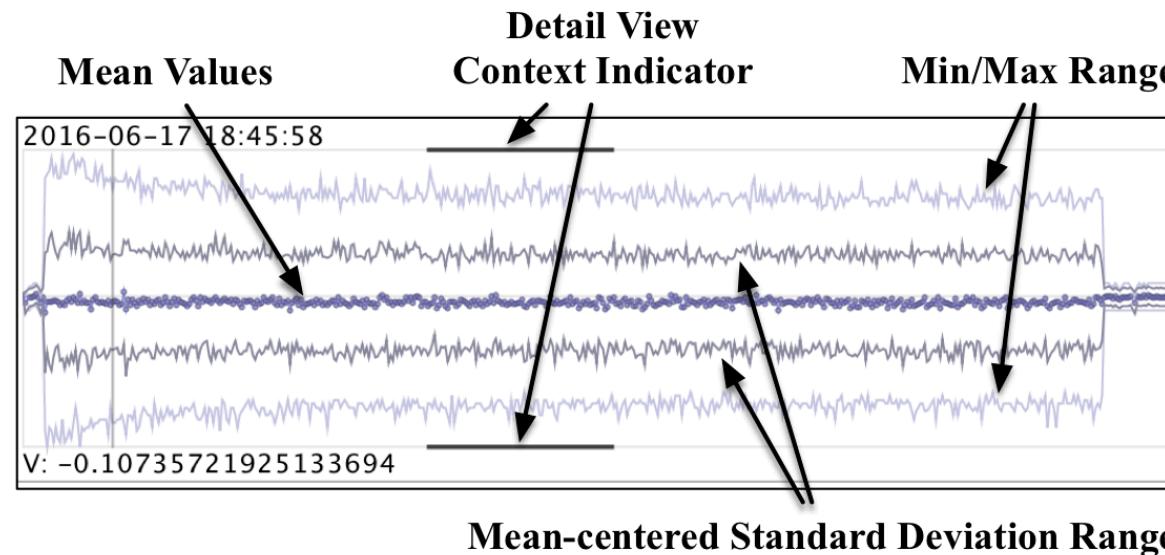
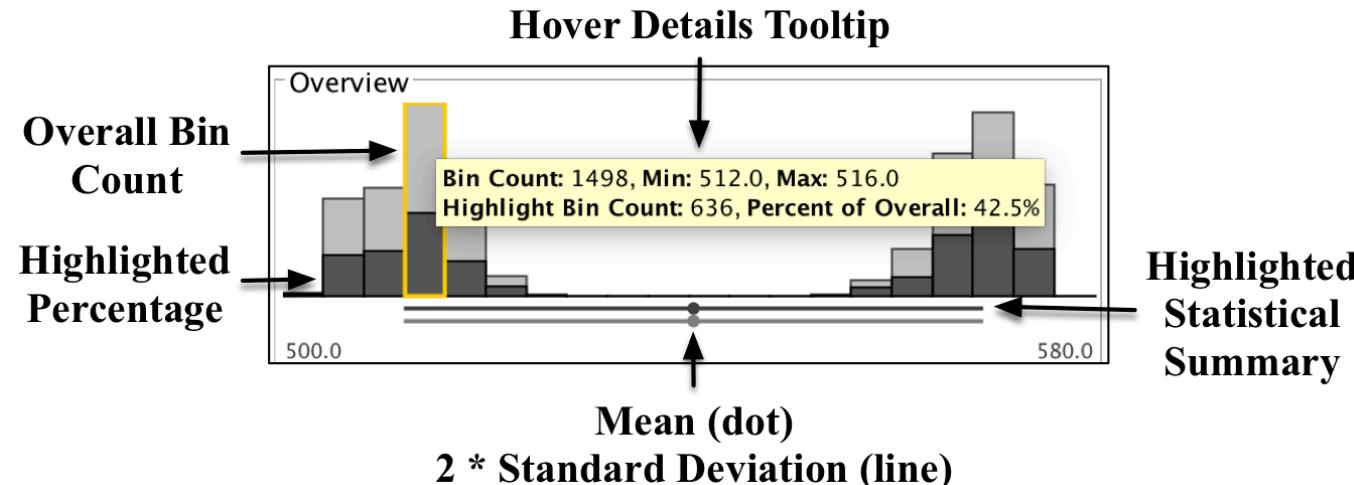


Variable Visualization Panel

- Consists of 1 detail visualizations and 2 overviews for a particular variable of interest (stacked for multiple variables)
- Interactions within each view are linked
- Details-on-demand capabilities

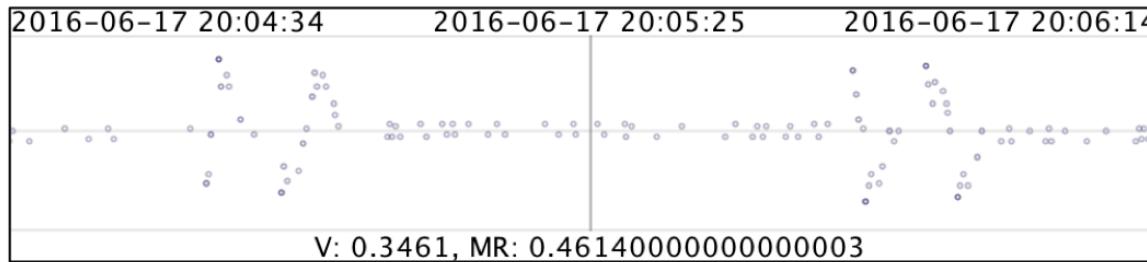


Overview Variable Visualizations

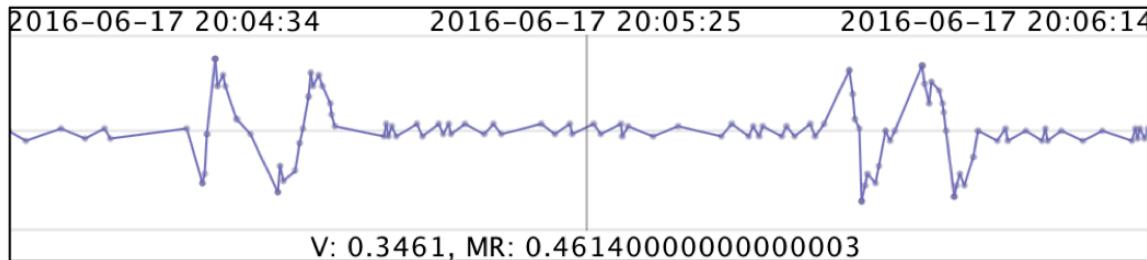


Detailed Time Series Visualization Modes

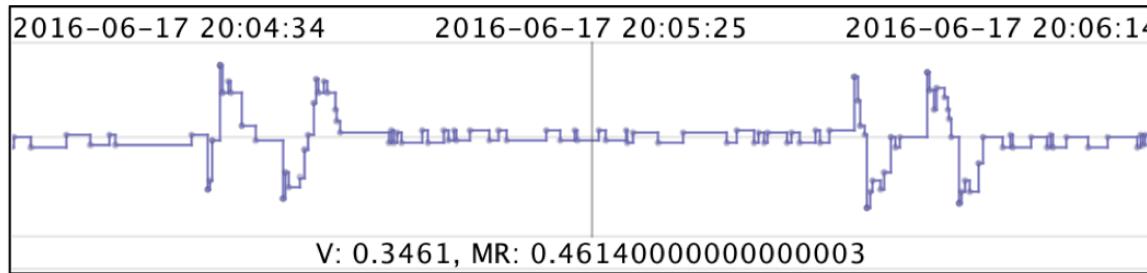
Point



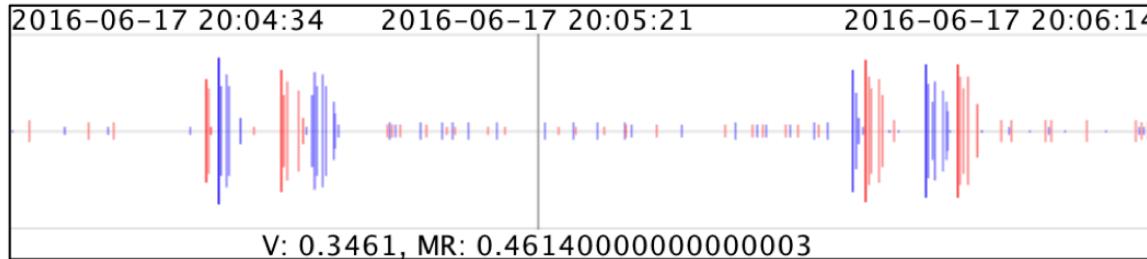
Line



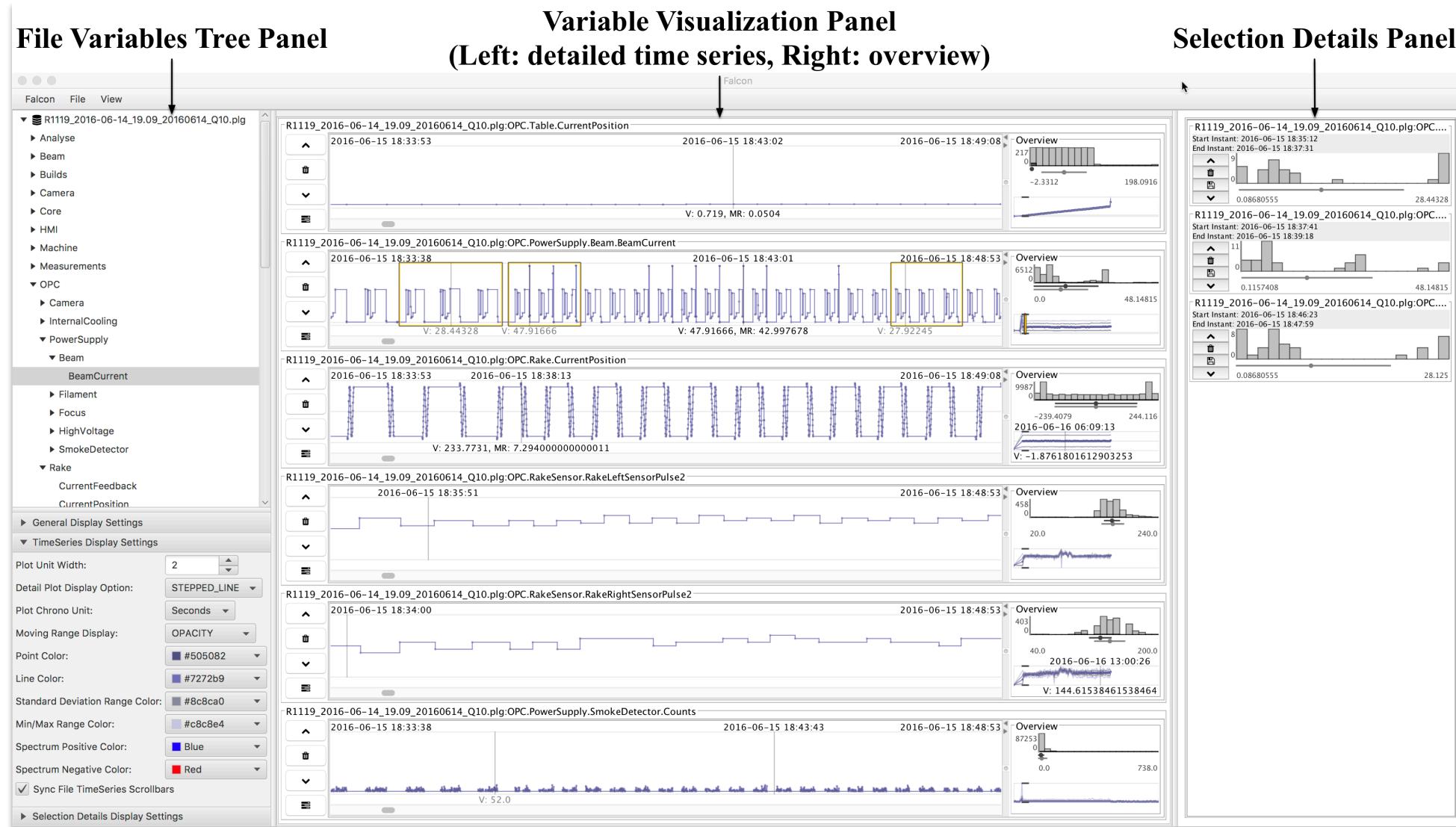
Stepped Line



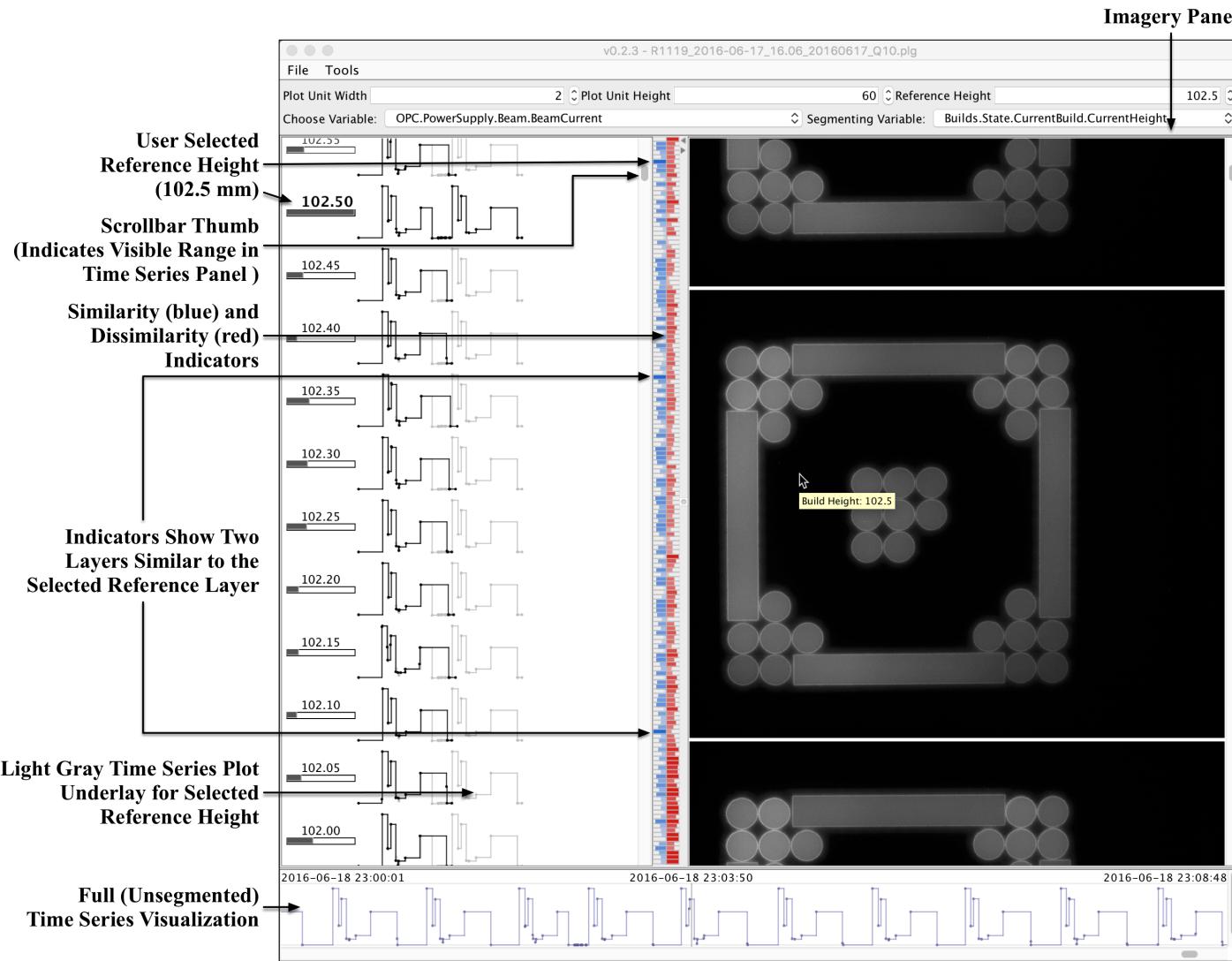
Spectrum



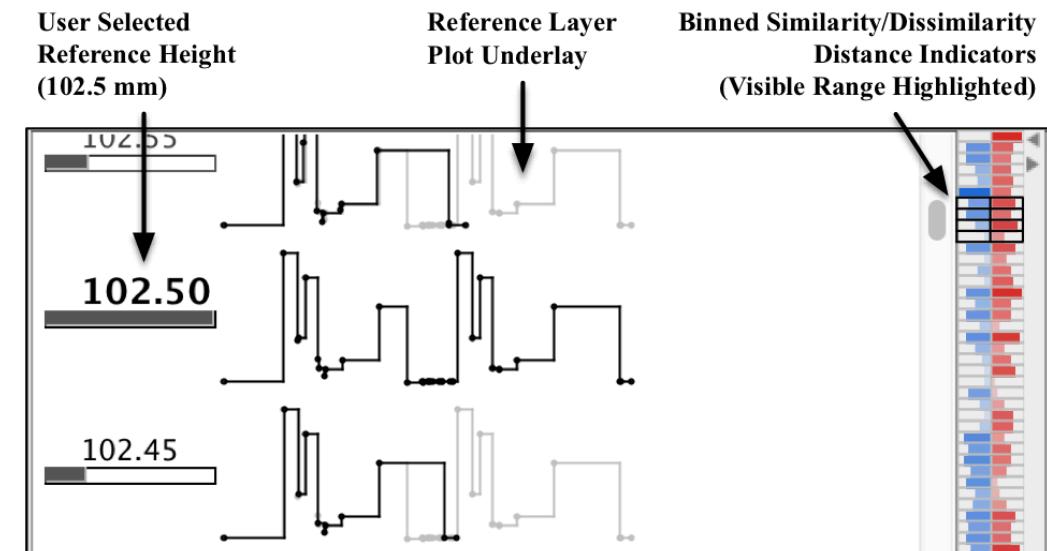
Selection Details Visualization Panel



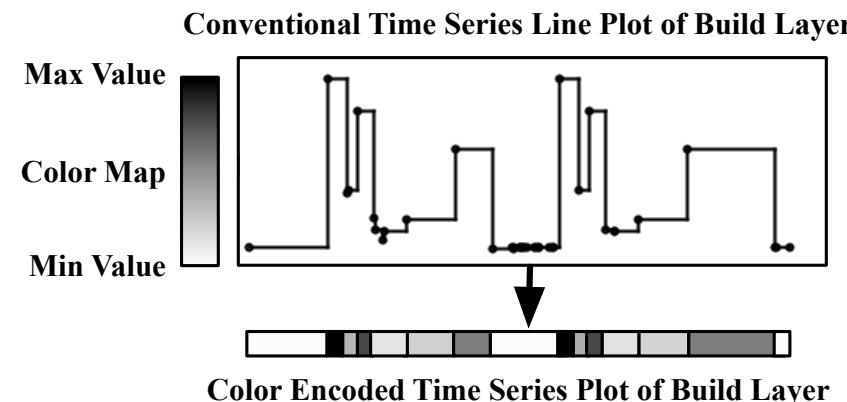
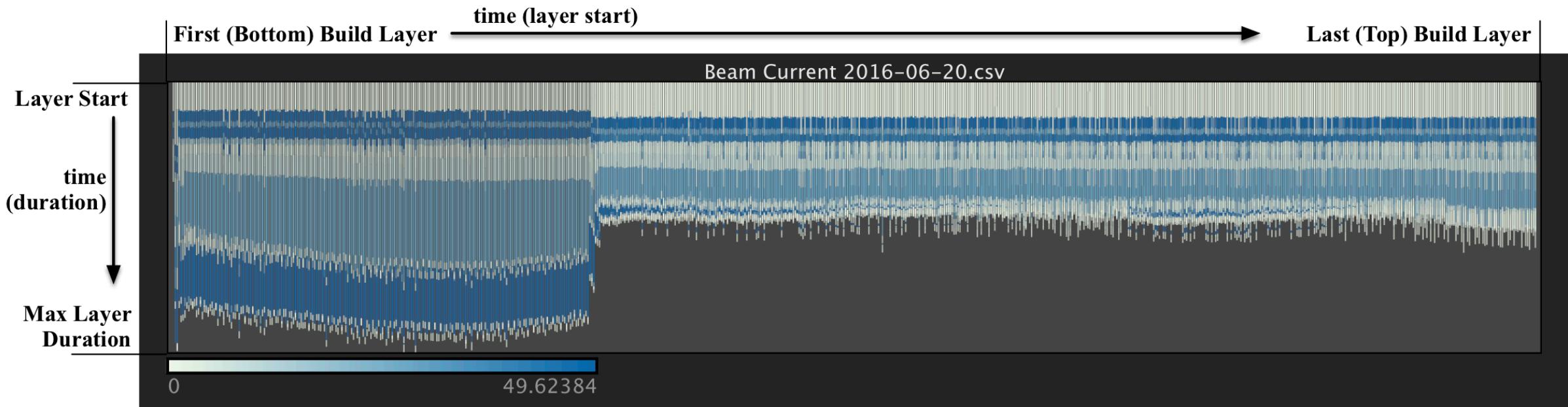
Segmented Time Series Visualization (Layers + Imagery)



Closeup of Similarity Metrics

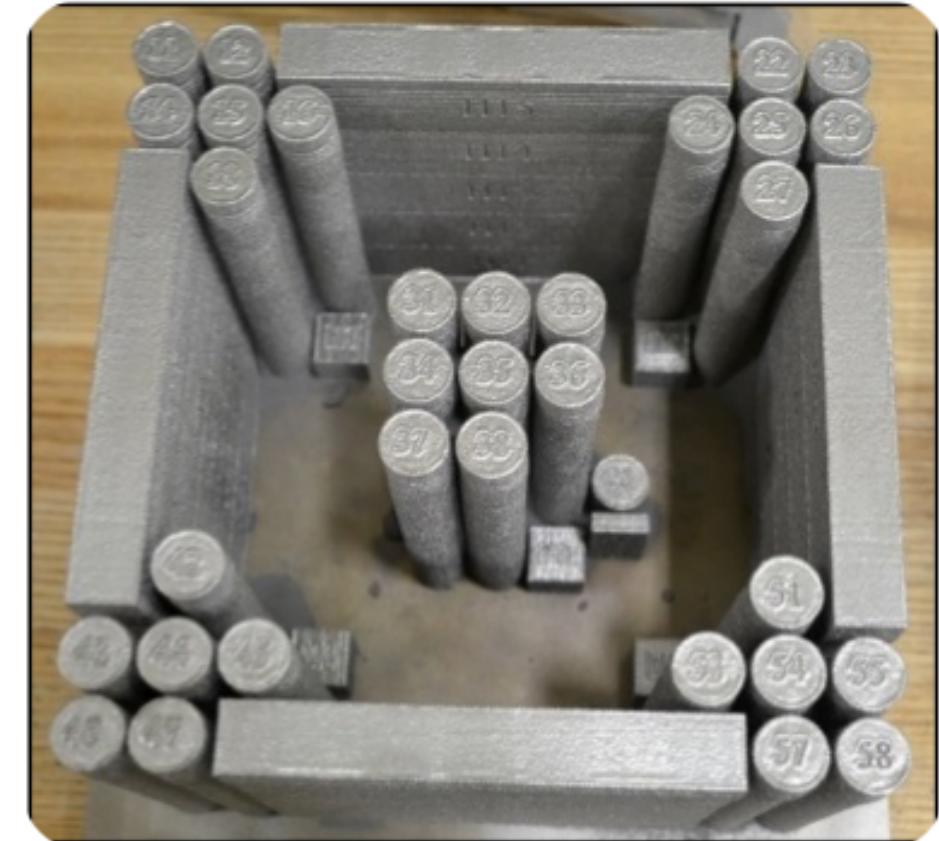


Waterfall Visualization (DNA Plot of a 3D Print)



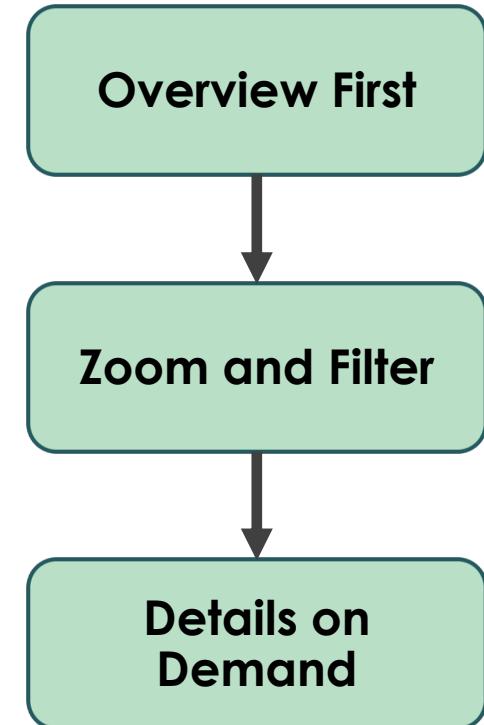
Case Study: Analysis of 3D Printer Build

- Arcam Q10 3D Printer System
 - Uses electron beam melting to synthesize metallic objects
- Data from the build of a special test configuration used to ensure the Q10 system is functioning properly
- Four distinct geometrical layouts and 5 specific features
- Created entirely from the build platform without support structures



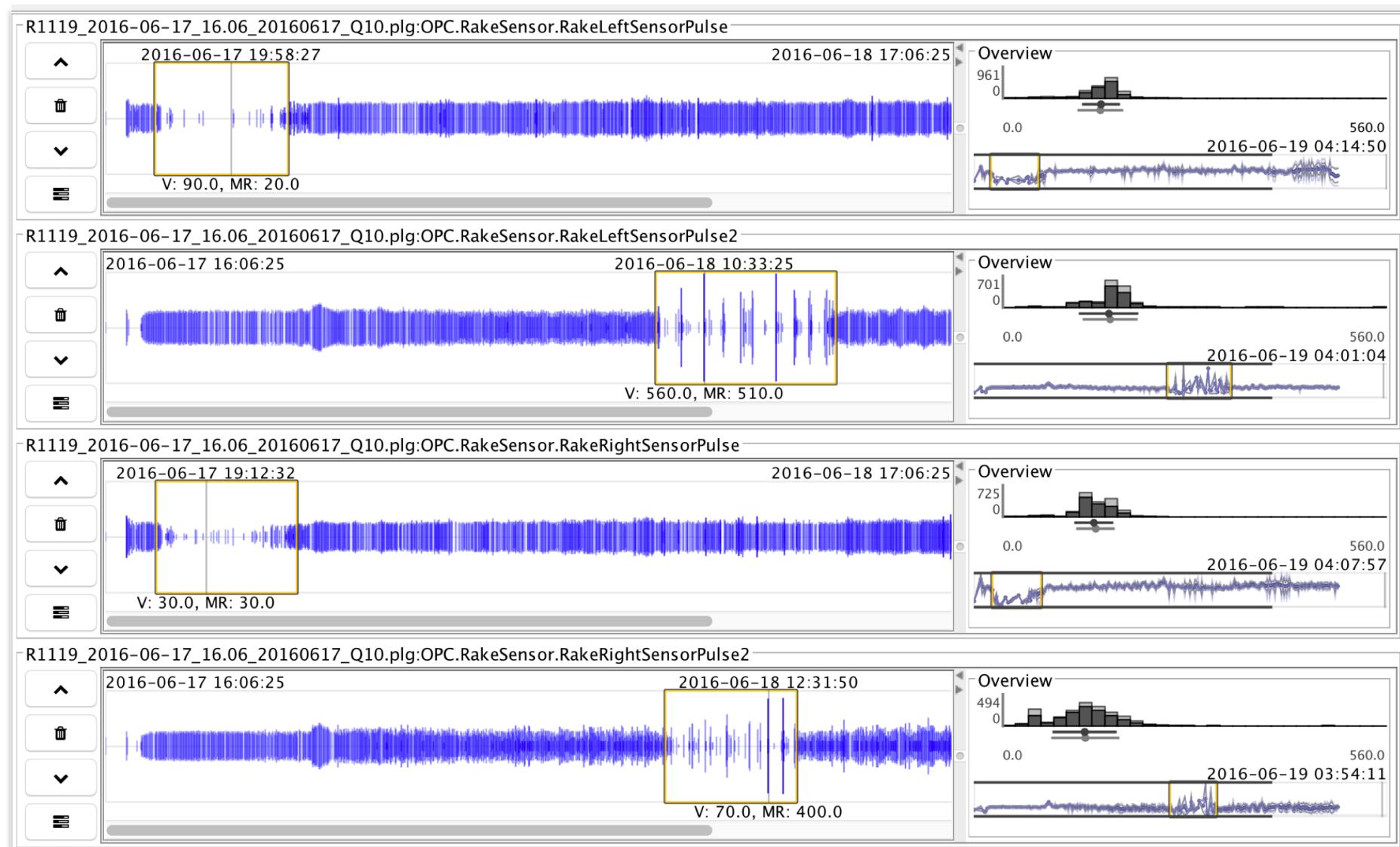
General Analysis Strategy Using Falcon

- Researchers naturally gravitated toward a workflow that parallels Shneiderman's visual information seeking strategy*
- Begin with overview of key variables
- Drill down to explore patterns
- Note interesting patterns and trends along the way
- Combine log and imagery data for big picture
- Follow-up with physical investigations to validate findings (e.g., scanning microscopy)

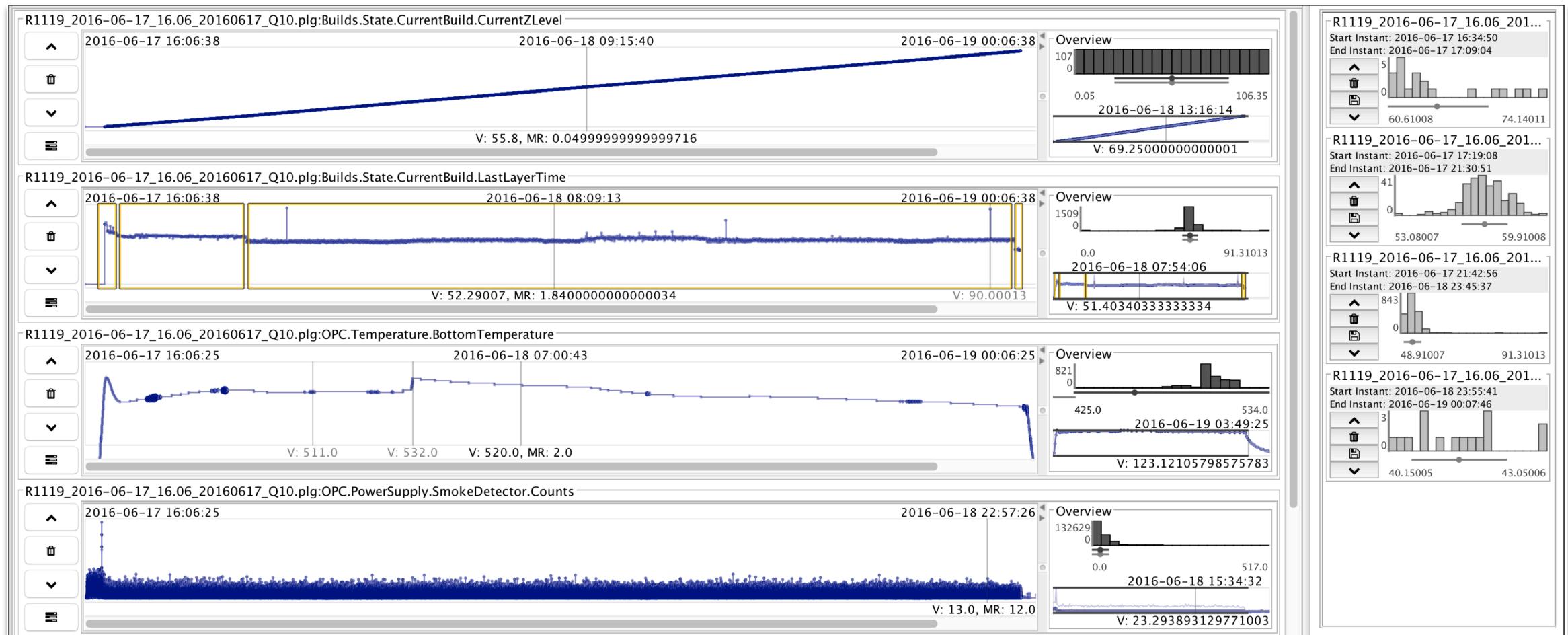


* B. Shneiderman. "The eyes have it: A task by data type taxonomy for information visualizations." In Proceedings of the IEEE Symposium on Visual Languages, pp. 336–343, 1996.

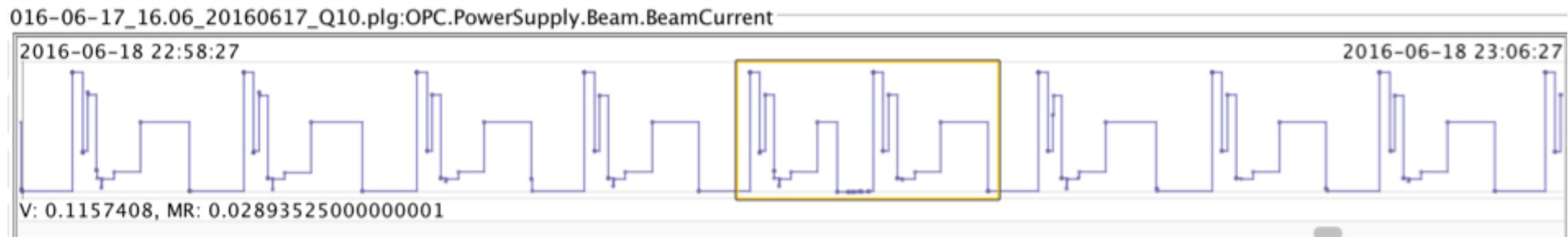
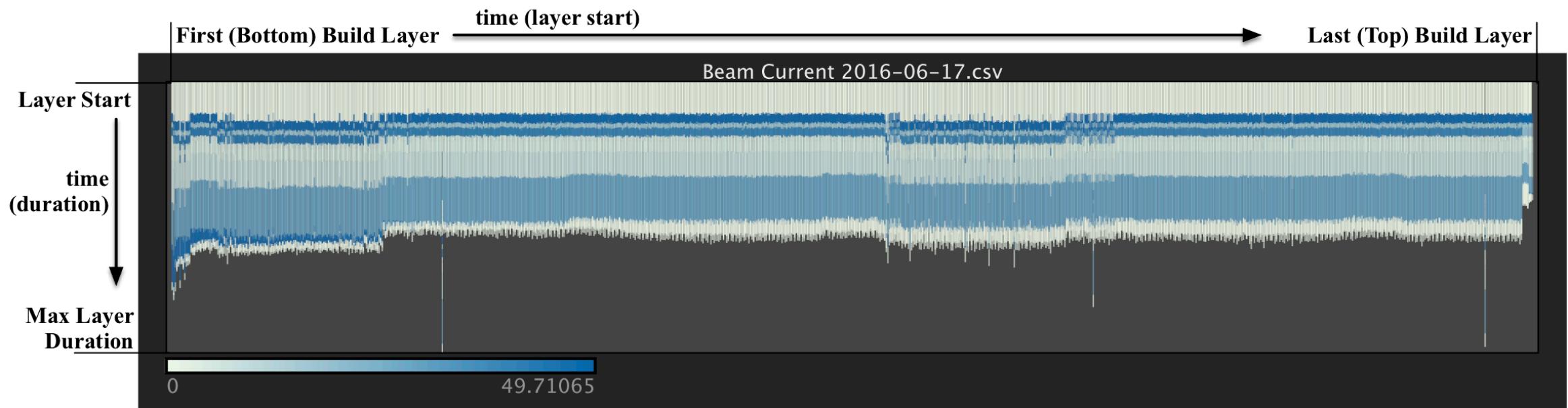
Overview First



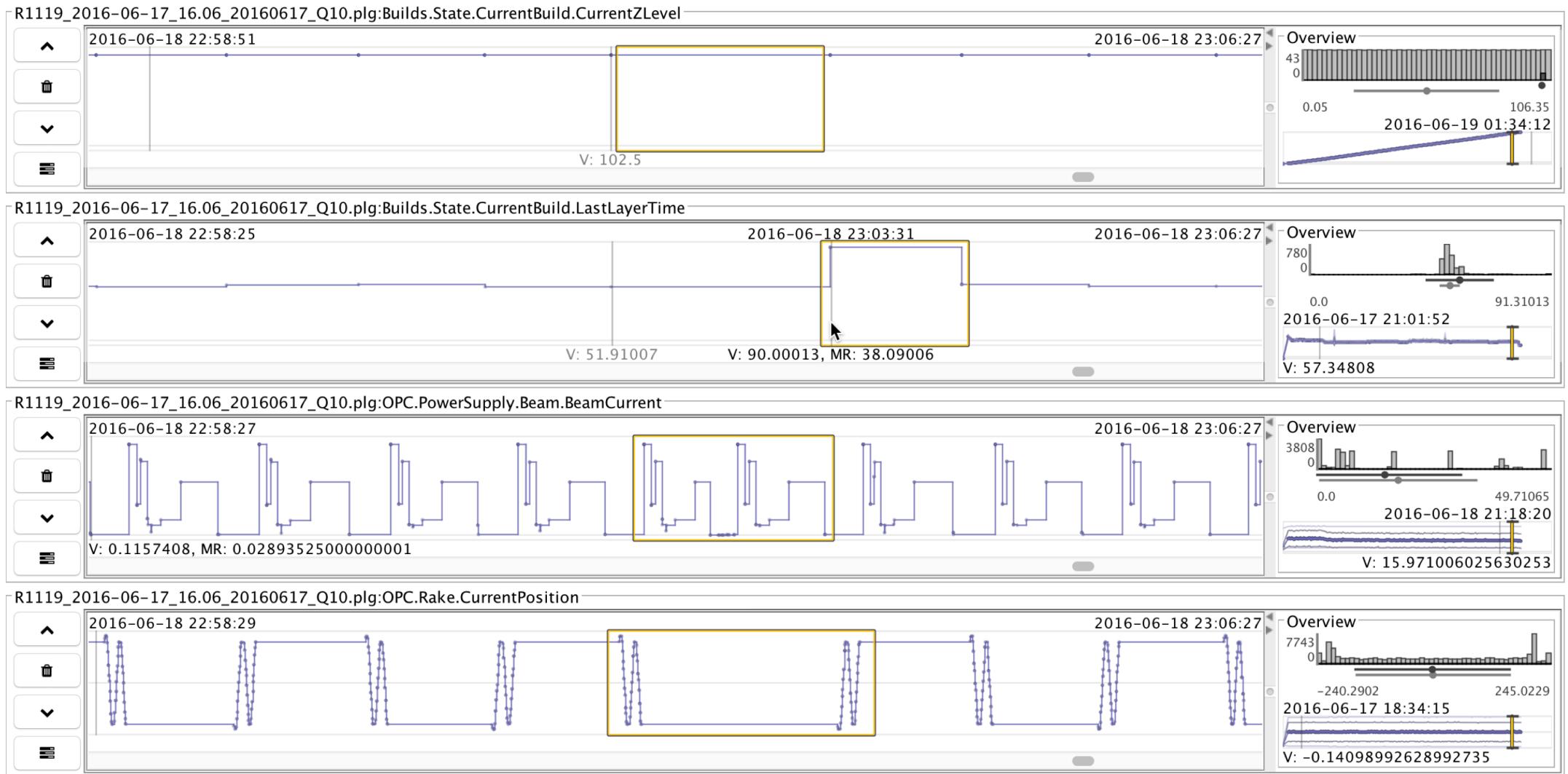
Overview First



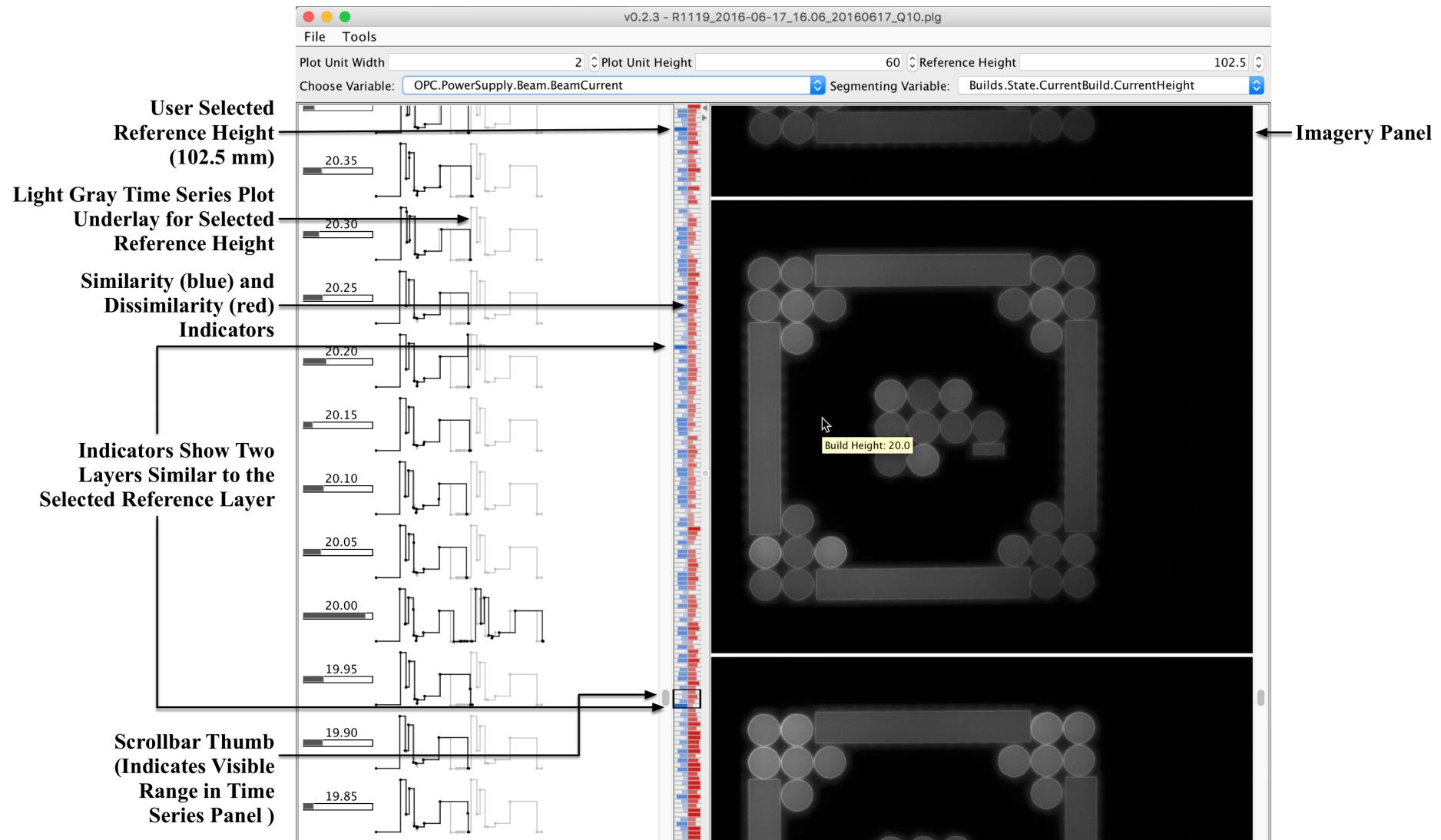
Overview for Particular Variable (Electron Beam Current)



Zoom and Filter

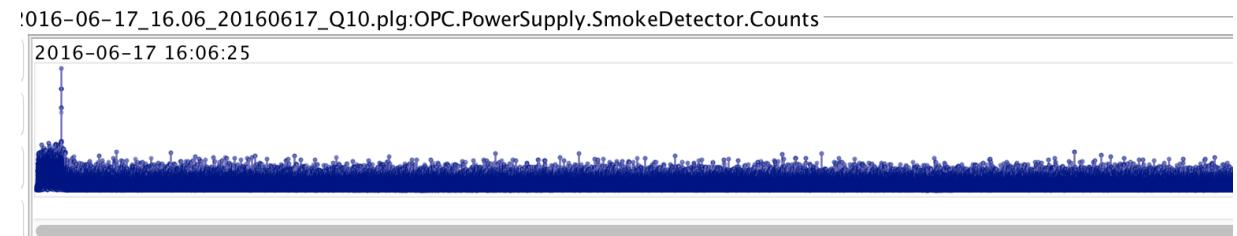
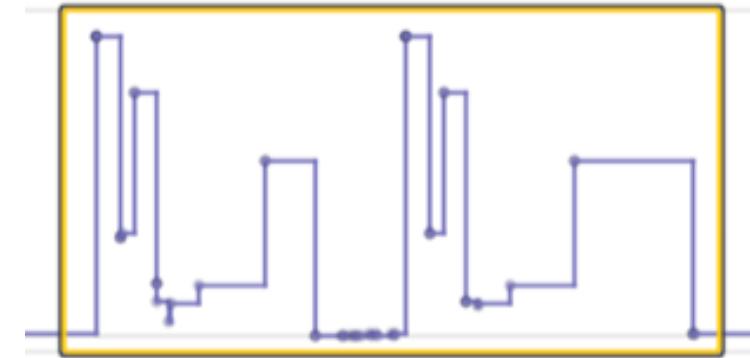
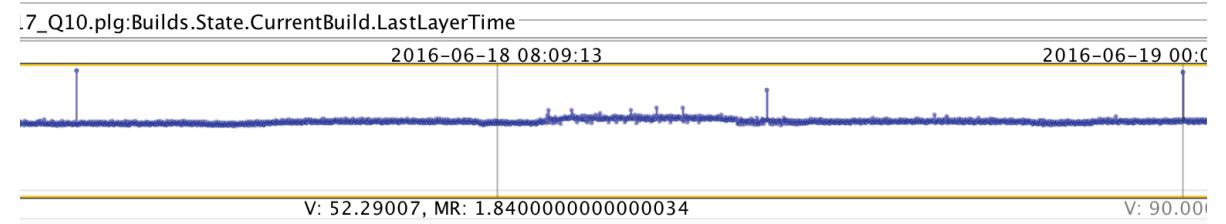


More Detail, on Demand



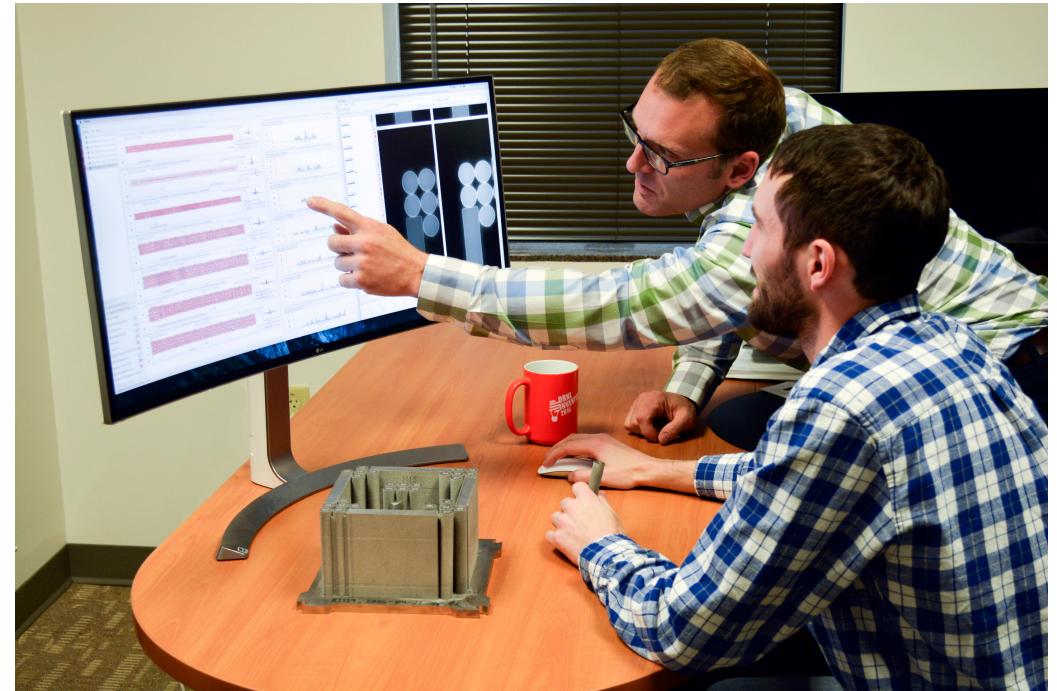
Identifying the Cause of the Outliers

- Two possibilities:
 - Smoke Detector Reset
 - Arc Trip
- Both cause signal repeats
- Here, arc trip is the cause
- This insight led to additional study to see how arc trips affect the microstructure of a build.

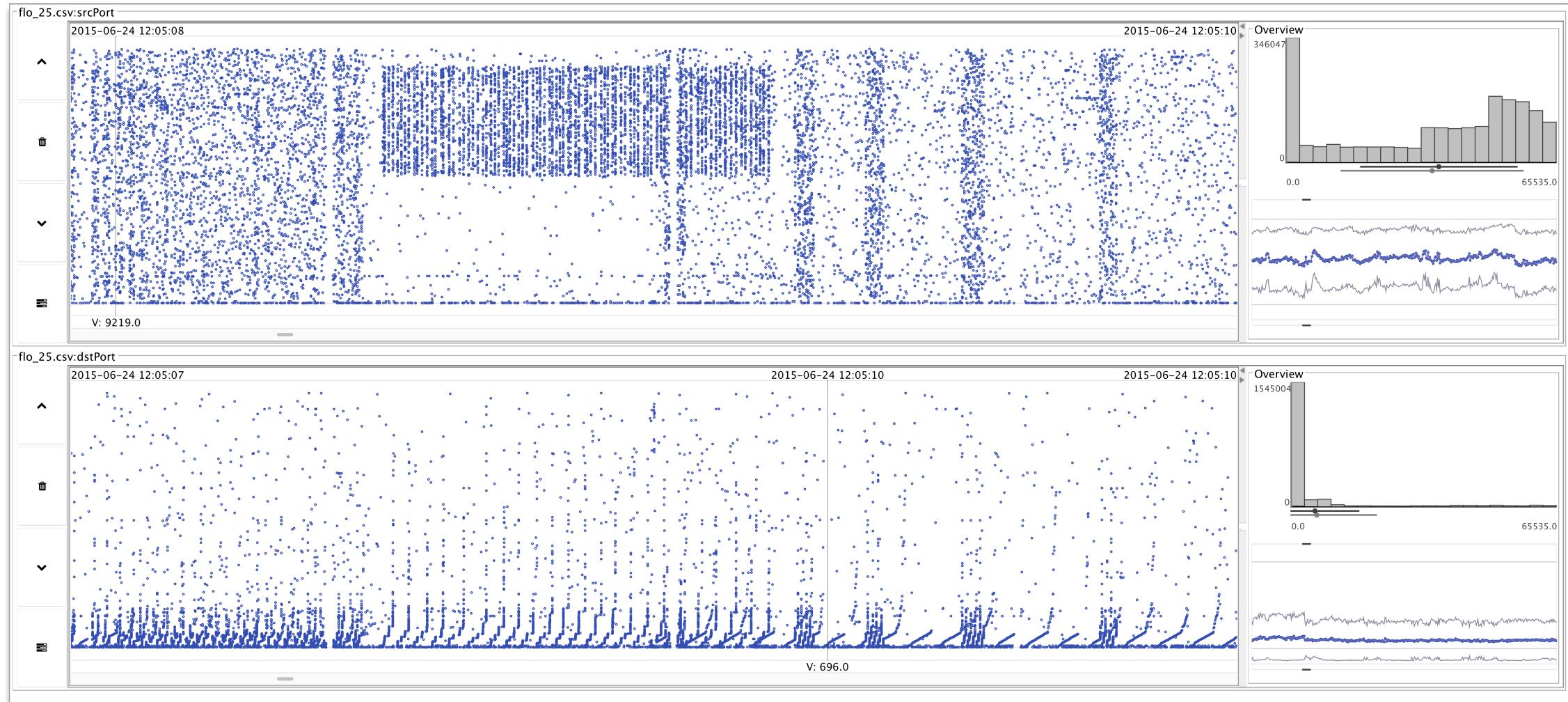


Discussion

- Participatory Design works well
 - Co-designed system features
 - Domain experts vested in the work
 - General vs. domain specific capabilities
- Limitations / Future Work
 - Session saving capabilities
 - Automated provenance tracking
 - Expanded multivariate visualizations
 - Automated pattern matching algorithms

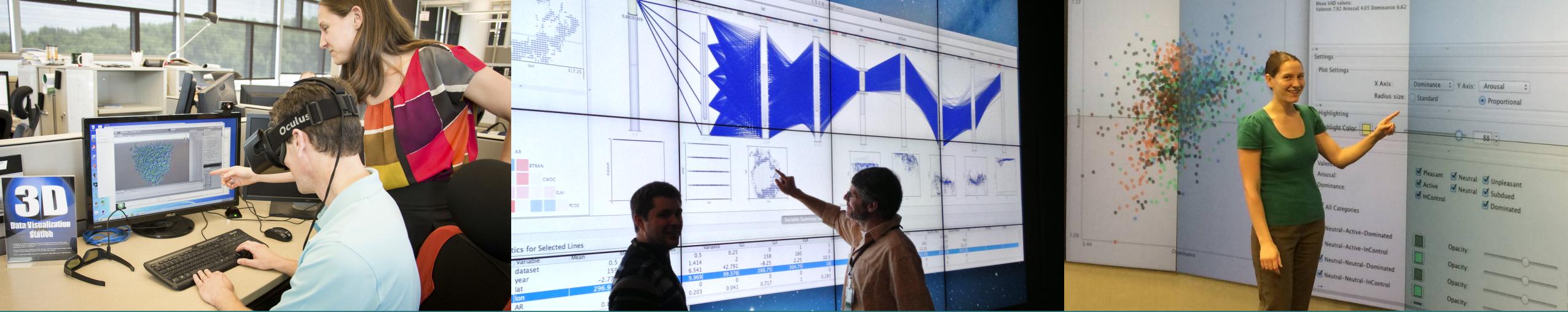


Other Applications (Network Flow Analysis)



Conclusions

- Falcon enables significant discoveries that:
 - Help us formulate future automated predictive analytics
 - Help improve understanding of complex multivariate relationships
- Falcon has already enabled improvements to the 3D printing process
 - Practical results demonstrate improvements over traditional, general purpose tools
 - Readily available (open source) and applicable to other domains.
- Advantages of following the InfoVis Mantra
- Strive to include domain experts in new data science research



Questions?

