Reliable Visual Analytics as Part of a Process Quality Assessment

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Overview from Abstract

In this contribution, we assess the strengths and weaknesses of *big data and visual analytics science and technology* VAST in the context of verification and validation.
This includes various *interaction/collaboration methodologies* and *mixed reality platforms* where scientists of different disciplines interact with each other, with data and information.
We discuss the possibility of a *multilayer quality assessment* procedure bearing in mind the methodologies from the neighboring fields concerning *reliability, accuracy, performance, efficiency, group activity monitoring as well as validation and evaluation*, similar to that from data analytics.
Further topics include *appropriate hardware devices* managing, for example, *safe data transfer*, and adopting concepts from *cognitive and perceptual sciences*.

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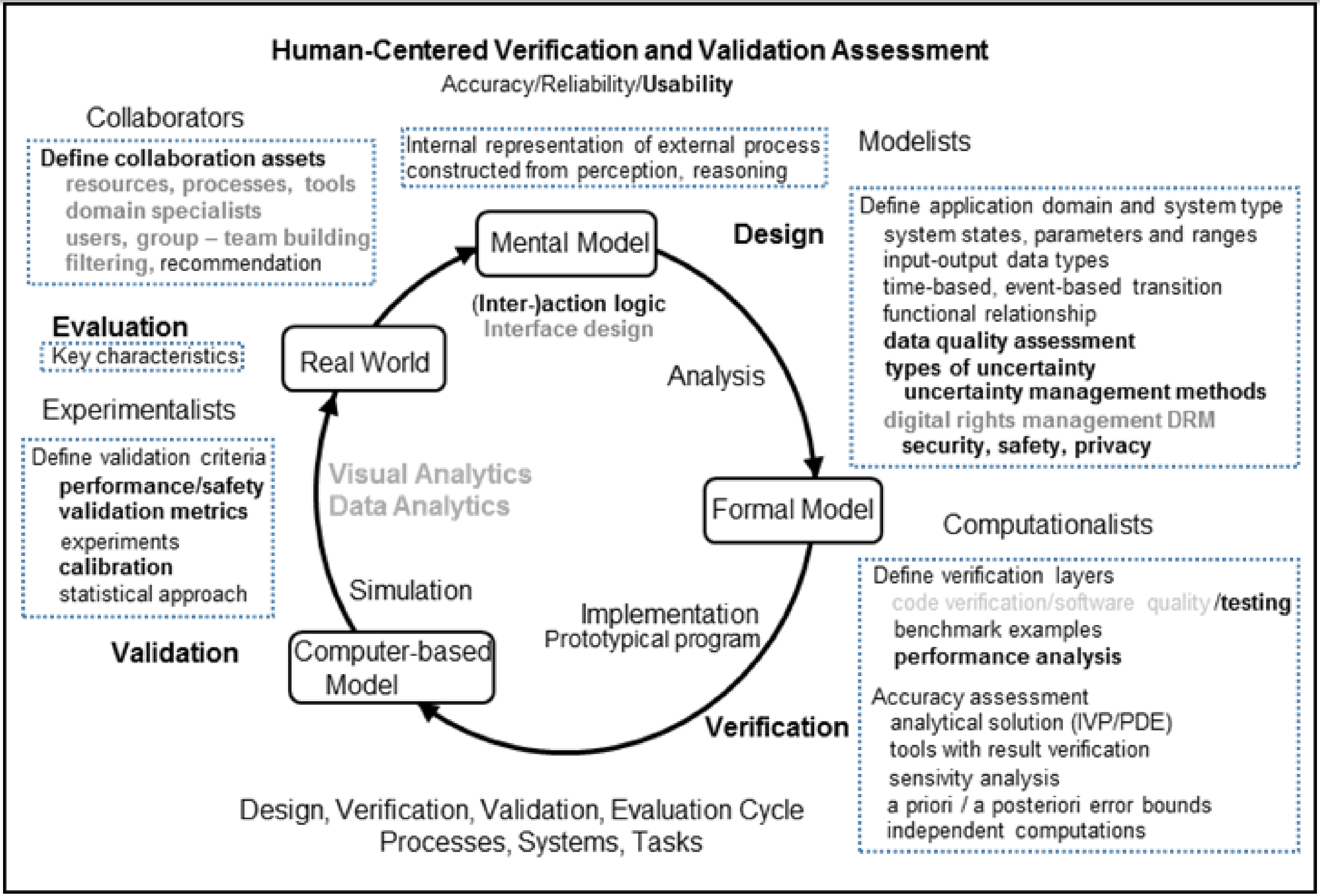
Introduction

- Real world process/system modeling and simulation
  - Various modeling, implementing, and evaluating approaches
- Application of V&V assessment to improve reliability
- Visual Analytics Environments
  - Ensemble data from independent process runs → Various analysis goals
    - Collecting, processing, classifying, displaying uncertain data
  - Visual layout and mapping, model-based analysis and interaction techniques
  - Human perceptual and cognitive capabilities + advanced computations
  - Various representation technics depending on artifacts' descriptors
  - In most cases, (result) verification and reliability is not an issue
- Evaluation scope focusing on users, models, and data
- Adapted interfaces, navigation and query techniques
- Toolchain for the whole software support

Visual Analytics Environments

- Complex processes use/produce huge, heterogeneous data
- Variables and parameters exhibit aleatoric and epistemic uncertainty propagated through process/systems states
- Important issues are user-controlled selection of data types, problem solving approaches, design of human-machine interaction and collaborative sense-making processes
- Hierarchical ensemble data are
  - Used in process model descriptions
  - Processed by sophisticated software tools
  - Displayed using repeated multiple views or incremental approximation
  - Analyzed in various ways to rate the process outcome
- Various evaluation approaches
  - Rule-based, role-based or knowledge-based
  - Usability: interaction style, task model, data handling, perception
  - Verification and validation taxonomy for computerized system models

State of the Art V&V Assessment



Towards Reliable Analytics - Evaluation of VAE

- Experts uses evaluated VA environments for validating computer-based processes or systems – aligning three models
- Uncertainty characterization using geometrical forms/glyphs or statistical descriptors
- (Simultaneous) use of both automated and manual data mining techniques; algorithms perform only a partial analysis supervised and supplemented by a human
- Graphical representation possibilities for results combined with structuring options
- Possibility of trend analyses
- Needs a platform for data fusion, sense and decision making and reporting.
- Evaluation approaches for multi-purpose VA frameworks
- Empirical studies in information visualization
- VAST challenge (2006-2014): crowd "decides upon the right metrics to use, and the appropriate implementation of those metrics including datasets and evaluators."

J. Scholtz, Developing Guidelines for Assessing Visual Analytics Environments, Information Visualization 10 (3) 2011, 212 -231

Dimensions, Quality Criteria, Metrics

- Reliable Computing
  - Dimensions: Numerical result verification
  - Quality criteria: The use of computer-based proofs, analytic solutions, algorithms using interval arithmetic, guaranteed error bounds, sensitivity analysis,….
- Reliable Data Analytics[1]
  - Dimensions: Reliability, Availability, Usability, Relevance, Presentation Quality
  - Criteria for Availability: Accessibility, Timeliness
  - Requirements: Existing access interface, data arrive on time, regular update, collecting and preparing for processing meet time constraints
- Validation
  - Purpose of computer-based model
  - Requirements
  - Metrics

[1] Cai and Zhu: The Challenges of Data Quality and Data Quality Assessment in the Big Data Era

Assessment Using Visual Analytics Environments

- *Reliable Visual Analytics*
- rate the formal strength of the computer-based process/system model descriptions as realization of a mental model w.r.t.
- - *accuracy* (fidelity of mapping, integrity, consistency, uncertainty capture)
- - *usability* (presentation quality, navigation/interaction, readability, recommendation, security, privacy, confidence)
- - *adequacy* (resources used for purposes)
- - *efficiency, performance and intuitiveness* (environment, analytical process, interaction, presentation)

- ....

- based on requirements, rules, metrics, benchmarks or specified user tasks (group building, process outcome analysis, sense-making/data fusion, knowledge creation, reporting).

Explanations, Definitions

- Accuracy – data used or provided are correct w.r.t. implemented data types
  - Needs ground truth, a reference or guaranteed bounds, calibration
  - *Consistency* needs logical relationship between correlated terms, items
  - *Fidelity* needs measurement methodology and (semi-)formal object descriptions; fidelity measures realism or degree of similarity, mapped objects must preserve properties, descriptors are equally perceived and rated
  - *Integrity* assessment rates appearance, depends on context: item should correspond to formal description, fulfills standards, is not modified
  - *Uncertainty capture*: data type deals with uncertain values, algorithms quantify and propagate uncertainty, assessment needs a notation and taxonomy for uncertain data visualization, interface supports interactive exploration and decision making under uncertainty
- Usability
  - Presentation quality: guidelines for visual depiction of data depending on set sizes and display formats, color, contrast, position, size, style, labels. Various visualization techniques, metrics based on time and accuracy, memorability

Vericomp - Comparing IVP Solvers

A web-based platform for comparing verified initial value problem (IVP) solvers for systems of ordinary differential equations

Visual aids such as work-precision diagrams to assess the

- usefulness of the verified solution provided by a particular solver (quality criterion: tool provides tight bounds)
- performance of the available solvers on problems from certain classes
- sensitivity to different characteristics (e.g., problem parameters, certain option settings, etc.)

VERICOMP can be used for facilitating such cooperative projects as ARCH-COMP

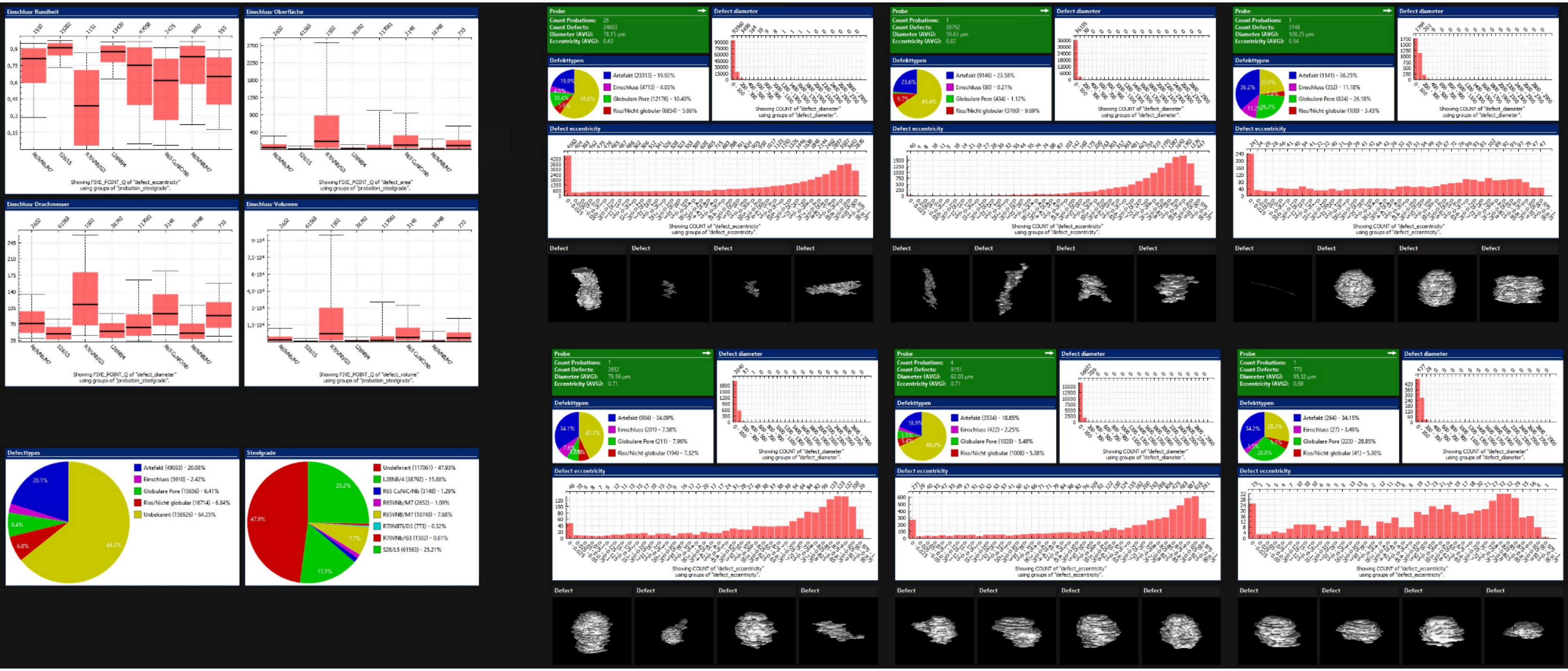
More information on Friday, 11:50-12:20 a.m.

SILENOS (UDE-HKM-Salzgitter Mannesmann)

- Process Parameters: Intentional settings or measurements taken during monitoring of various steel grades and their metadata
- Defect parameters, descriptors and volume data for each defect:
  - Isoperimetric shape factors: Volume V, surface area S, mean curvature M, Euler number X
- Sample Parameters: Milling machine slices the steel surface; Statistical descriptors of the defects, such as the sample cleanliness
- 3D reconstruction of cracks, non-metallic inclusions or pores
- Trend and sensitivity analysis: How the defect data (positions, sizes, types, number) change depending on process parameters?
- Assessment topics
  - Ensemble Analysis tool: effectiveness, user satisfaction, learnability
  - Task work: adoption rate, usability, reliability, trustability
  - Visualization engine-repeated multiple views: utility, scalability, learnability
  - Incremental approximation: performance, optimal visualization parameter, accuracy

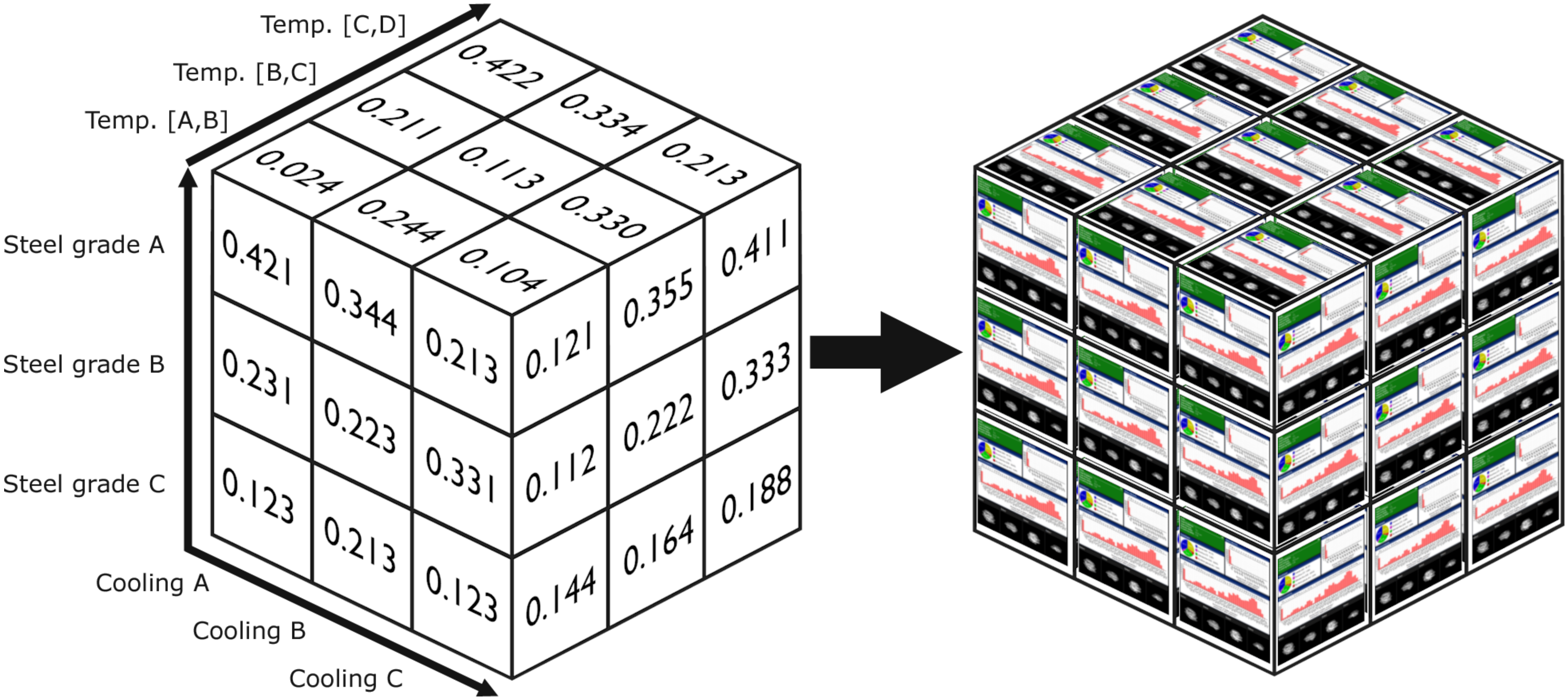
Topics assessed	Data quality and mapping	Descriptors	Tasks/Goals
Data and metadata model **Input data quality** **Data management**	Thousands of qualities Sample, defect parameters Ensemble data sets and subsets, set operations, analysis	Statistics in bins, max, avg, min Reference data descriptors	Trend and sensitivity exploration, Anomaly detection, Parameter correlation, Quality rating
Outcome classification - variance and uncertainty analysis	Defects: cracks, nonmetallic inclusions, gas pores Variances in defect parameters depending on smelting parameters	Spatial morphology Isoperimetric gestalt Uncertainty in defect parameters	Efficient computation of Minkowski functionals Sensitivity analysis Impact on steel quality
Performance of incremental analysis for large queries	Increasing accuracy of statistical plots, ranges of possible outcome	Correlation defect diameter and defect eccentricity	Analysis with 4%, 28% and 100% of the data used
Visual space design **Presentation quality**	Level traversal visualization can contain millions of grid cells by using view frustum culling	Eccentricity, defect diameter, groups of samples with certain defect diameter for various furnace smeltings	Single node analysis, grouping, aggregation Data tree traversal Grouping by samples or defects
Navigation, view point selection **Interaction, artifact manipulation** **Tree operations**	Preparation of data for interactive use Multiple view layout Coordinated/collaborative manipulation	Performance, Intuitive handling User satisfaction	Traversal, reference data selection, node aggregation, sorting and filtering

IPFViewer – Particle Detection/Analysis System



In the overview on the left, uncertainties of four different outcome measurements are shown for different steel grades (bar charts). Two pie charts show the distribution of two categorical attributes. On the right, each steel grade is visualized in greater detail using the same layout to enable comparison. Additionally, for every steel grade, four of the most significant defects are shown (M. Thurau, Chr. Buck, 2010-16).

OLAP (Online Analytical Processing) Cube

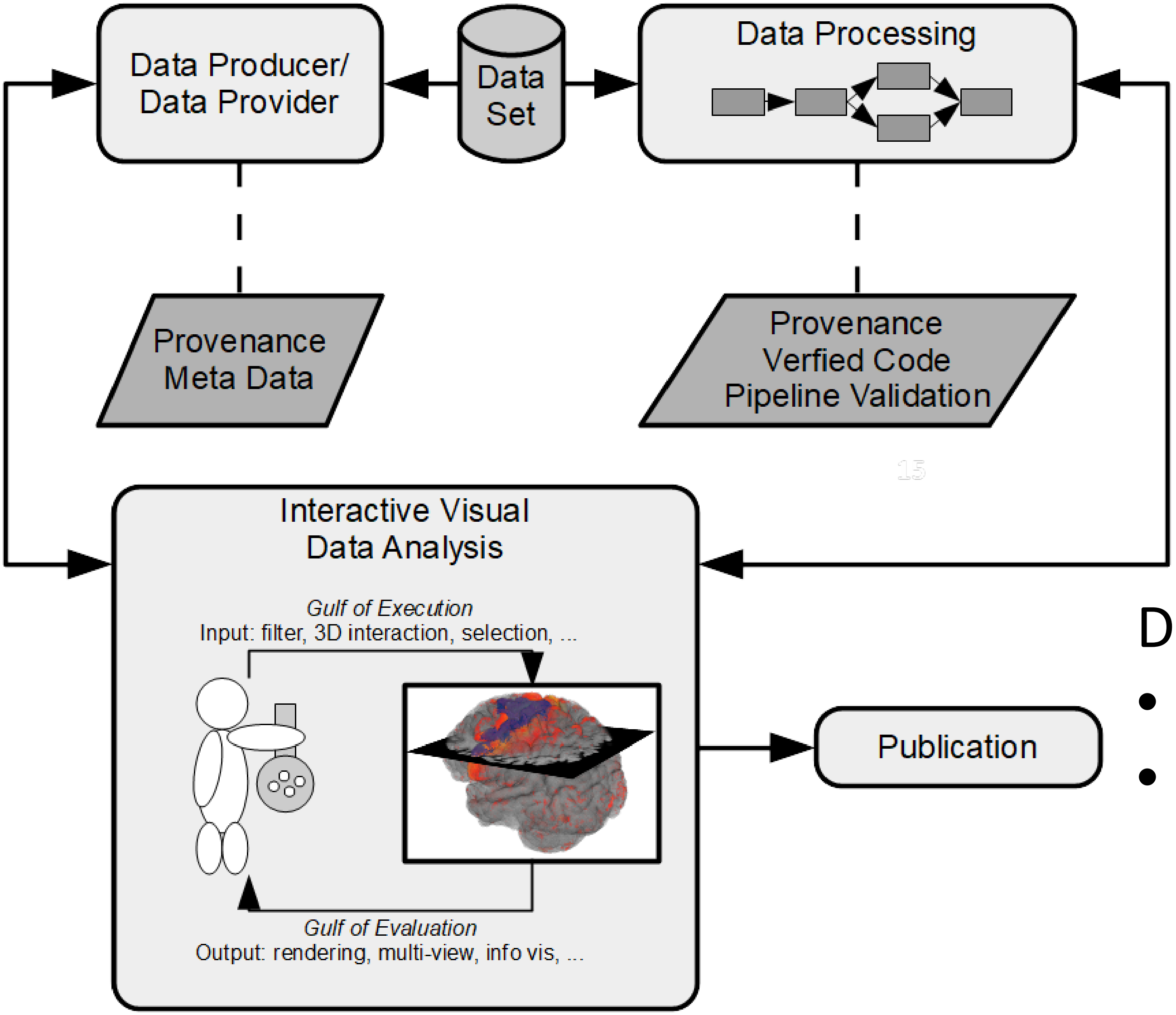


OLAP: average of sample cleanliness

IPFViewer: multiple view layouts

Multidimensional grouping comparable to OLAP cubes in real time. In addition to numerical analysis of the aggregates, the IPFViewer visualizes the data cells with repeated multiple views (flat on the screen) and presents the data mining results for each group.

Scientific Workflow Embedding Visual Analytics Tools



- Data Production
- Data Processing
- Visual Analysis
- Publication

Don Norman:

- Gulf of Execution
- Gulf of Evaluation

Reliability Analysis Framework - Dimensions

- **Visual Integrity (VI):**
  - Tufte's definition, e.g., including the lie factor which is a mismatch between effect size in the data and size of the representation of this effect
    - Data format of visual variable, graphic dimensionality, uncertainty
    - More general principle: graphical excellence: clarity, precision, and efficiency
- **User Interface (UI):**
  - All potential operations to be applied to the visualization → Defines the potential exploration space
- **Interactive Analysis Process (IP):**
  - Defines the set of processes to analysis the data

All embedded into the context of

- User's task, goals, & experience (UX)
- Organizational context

Reliable Visual Analysis Framework – Quality Criteria

- **Accuracy (AC):** may be defined as the potential of error prevention the visual analytics system offers.

- **Adequacy (AD):** may be defined as the level of suitability of the visual analytics system for the general analysis question.

- **Efficiency (EF):** may be defined as the performance the visual analytics systems enables for the general analysis question.

Human-Centered Reliable Visual Analytics

Reliability \ Quality Criteria	Accuracy [AC]	Adequacy [AD]	Efficiency [EF]
Visual Integrity [VI]	- Correctness - Mapping	- Mapping - Design	- Readability - Layout
User Interface [UI]	- Readability - Intuitiveness - Ergonomics	- Perceivability - Usability	- Usability - UX
Interaction Process/ Dialog [IP]	- Intuitiveness - Learnability - Robustness	- Complexity - Structure - Mapping	- Seq. Length - Usability - UX

Reliable Visual Analysis Framework – Quality Criteria

- The various measures are assessed iteratively and empirical using various methods:
  - User tests and studies (think aloud protocol, usability questionnaires, etc.)
  - Expert interviews
  - Formal modeling methods, e.g., in case of the user interface, the task, or the context
- Formal modeling enables to validate user interfaces and systems against requirements and specifications

Conclusion and Further Work

- Reliable Visual Analytics as part of an enhanced V&V management was introduced and applied within a workflow for designing, modeling, and implementing various processes
- Various dimensions of reliability and quality criteria, task model and interaction styles, metrics, rules and requirements were discussed, but final definition are missing
- Toolboxes for the spatial decision making, steel artifacts, femur prosthesis, virtual labs, traffic simulation etc. were realized for supporting reliable visual analytics
- Guidelines with benchmarks and measures to rate mental and computer-based models are future work (auditability)

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Toward Reliable Analytics - Evaluation of VAE

A group of experts uses evaluated VA environments for validating computer-based processes or systems with the main goal of aligning validation issues, simulation results and the mental model.

The advantages of using VA techniques for this purpose are the following:

– working with big amounts of heterogeneous data on results in an efficient way

– uncertainty characterization for the computer program through visualization using geometrical forms/glyphs or using statistical descriptors such as moments

– possibility of trend analyses with time

– (simultaneous) use of both automated and manual data mining techniques; the possibility to let algorithms perform only a partial analysis supervised and supplemented by a human

– a huge choice of graphical representation possibilities for results combined with good structuring options

– a platform for data fusion, sense and decision making and reporting.

There are various evaluation approaches for multi-purpose VA frameworks based on empirical studies in information visualization or community activities, e.g., Visual Analytics Science and Technology Challenge (2006-2014) created as a community evaluation resource: “decide upon the right metrics to use, and the appropriate implementation of those metrics including datasets and evaluators.”

Application Software

- Steel application → analyzes data collected about non-metallic inclusions and other defects in steel samples: Image processing, Particle Detecting and Analysis System, Inclusion Processing Framework Viewer IPF 2.0 (Chr. Buck, M. Thurau, 2011-2016)
- ViMEDEAS → Virtual museum/lab builder – validated (inter-)action logic (D. Sacher, 2011-2017)
- House of Risk → devoted to individual threats, thematically classified and placed in an indoor or outdoor context. It will also address public threats and macro-catastrophes etc. (A. & L. 2016 -)
- GIS-applications → Uncertainty modeling, traffic, localization, network planning (G. Rebner, B. Weyers, J. Frez, 2012 -)
- Femur prosthesis surgery → Data grabbing, reliable superquadrics modeling, visualization – integrated framework for verified geometric computations (R. Cuypers, St. Kiel, 2009 – 2014)
- Microscopic traffic modeling and simulation system → Code verification, model validation (J. Brügmann, 2013-2015)

Uncertain Data Visualization

- Taxonomy wrt. data dimension – domain, range of *f*
  - 1D (for scalars)
  - 2D, 3D (for spatial vectors)
  - ND (for non-spatial, multivariate, and time-varying data)
- Uncertainty added as a geometric form (line, bar chart, thick surface)
- Also: color maps, glyphs or isosurfaces (level sets) (unit of space - arrow, unit of color, number of graphical elements)
- More complex functional process descriptions are not included (Potter et al. 2012)
- Missing user interaction, requirements concerning hard-ware architecture or context detection, perception issues

Notation for Uncertain Data

Brodlie (1992, 2012) introduced E (exact),U (uncertain) notation, which also records the number of independent variables or parameters as a subscript and uses a superscript to indicate the type of dependent variables.

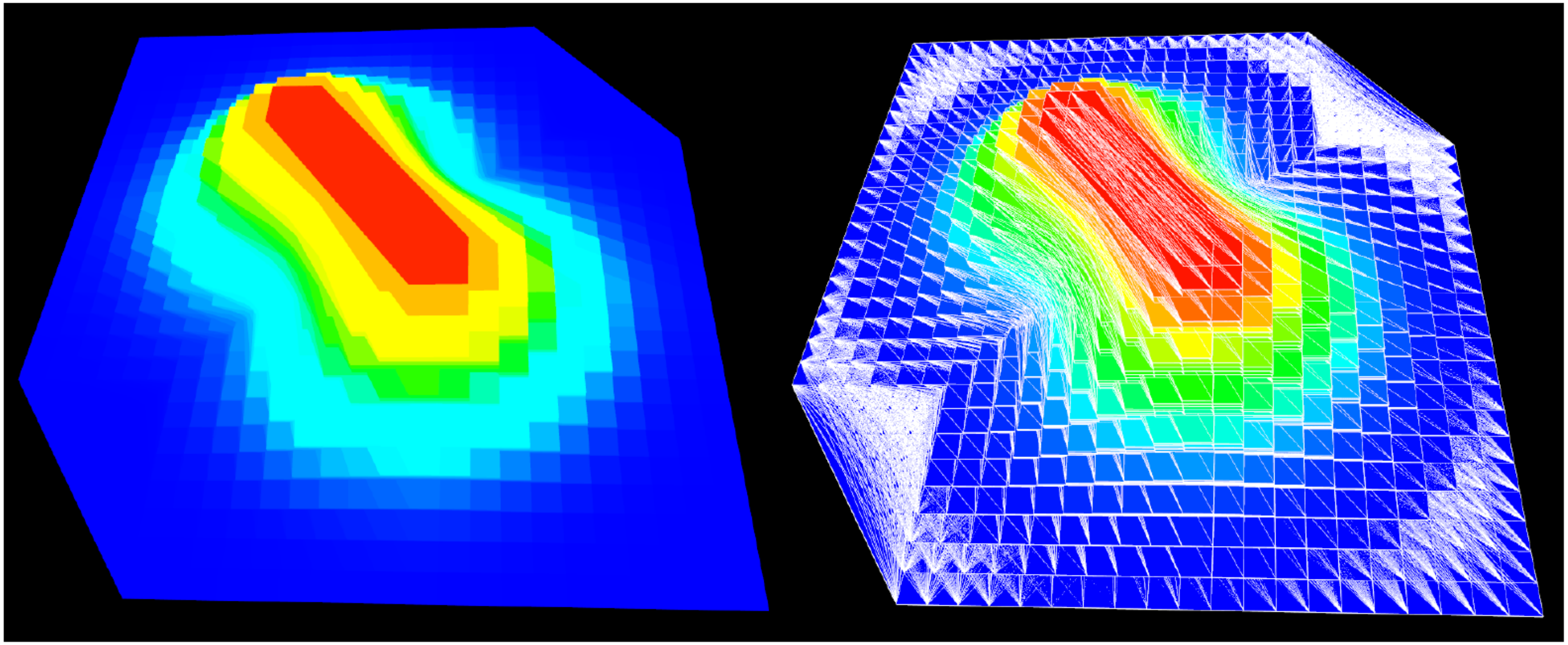
Examples

- E_1^S : scalar function of one variable
- E_1^{kS} : *k* scalar functions
- kE^S : multi-field scalar data ($E_{\geq 0}^{kS}$)
- E^V : vector data.

Examples

- Function (*x,y; f,m*), 2D earth map; seismic loss event frequency (color) and loss magnitude (size)
- Uncertainty contour band indicating the boundaries of the 95% confidence interval
- Diagram relation (*x,y; z*): E_{xy}^{z} with integer or alphanumeric data *x,y,z* or intervals (*x,y; v*): U_{xy}^{V}, *x* damage, *y* frequency, *v* acceptance (color)
- Uncertainty isosurface with color U_{xyz}^{V}
- Animation of diagrams over time E_{xyt}^{V}
- A set of relations (edges) between nodes visualized as a graph structure *S'*.

Uncertain GIS Query Based on p-Boxes



Graphical representation of the solution set describing possible locations and orientations of a truck.

Mapping for Real World Processes

More general: Ordered couples of *input-output data* $(d_{i1},\dots, d_{ik})$, $(d_{o1},\dots, d_{oj})$ and *metadata (descriptors)* $(m_{i1},\dots, m_{ir})$, $(m_{o1},\dots, m_{os})$ of the underlying relation (set) *R*, process *P* or structure *S'*

Selecting a few $d_{.j}$ or a projection *restricting* certain variables or parameters to a bounded interval, a set or a precise value of a variable (parameter) reduces dimension

Uncertainty U_x^V could be represented as an interval or error bar $\boldsymbol{z}_x$ over a discrete set *X*, a truncated upper and lower PDF or interval mean and the standard deviation of a PDF. Varying contour color or thickness and surface opacity illustrate regions of uncertainty across the spatial domain, often augmented with uncertainty annotations.

Human Computer Interaction - Interfaces

- Windows, icons, menus, pointing (WIMP) interfaces utilizing mouse and key-board-based interaction on screens are well suited for presenting 2D content
- Post-WIMP interfaces allow for new interaction paradigms for the navigation and manipulation of 3D Virtual Reality Environments and visualizations.
- They use 3D devices to navigate and select objects and to grab or grasp and manipulate items, e.g., an elastic arm and a virtual hand; users move around items, detect interesting viewpoints or areas of interest.

Task Models and Interaction Styles

- Extensions of the W3C task meta-model are needed to face new interaction styles, which do not depend on classical 2D UI elements. The meta-model offers a hierarchical structure among tasks and provides several operators to define temporal relationships between tasks
- Extended post-WIMP task models (PWTM) have to in-clude adequacy of interaction elements, flexibility in partitioning the task among multiple actors, multimodal fault-toleration and error-avoiding dialogues with forward and backward error recovery to cover uncertainty issues
- PWTM should have profiles depending on the application type, for example, cooperation or virtual reality.

Immersive Environments

- Vivid representation of objects, particularly real life scenarios, such as people walking in streets: traffic, landscapes, sport simulations, power plants or other technical processes
- Navigation, selection, surrounding and manipulation of items in a 3D environment
- Situational awareness and new forms of collaboration in problem management and decision making—shared workspaces, multi touch-tables, and co-creation
- Environment models seasons, day and night, weather, and various landmarks or navigation aids.