Building a usable visual analytics tool for network security[1]

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Network security challenges

- Increase in
  - Number of users
  - Variety of connecting devices
  - Diversity of communicating applications
  - Amounts of network data
- Layered security model
  - Firewalls, IDS/IPS, ...
  - Active monitoring typically supported by textual or semi-visual tools as well as home-made scripts
  - Efficiency and effectiveness of these tools is challenged by the high volume and complexity of data that is being generated

Visual analytics for network security

- State-of-the-art still necessitates computer+human solutions
- Visual analytics has emerged as a promising approach to deal with the data overload
  - Network data is processed and presented in a visualisation
  - Visualisation is interpreted by human, perhaps to identify possible attack traffic for further analysis
- Unfortunately, many proposed VA tools have failed to gain wide acceptance among network security professionals

Visual analytics for network security

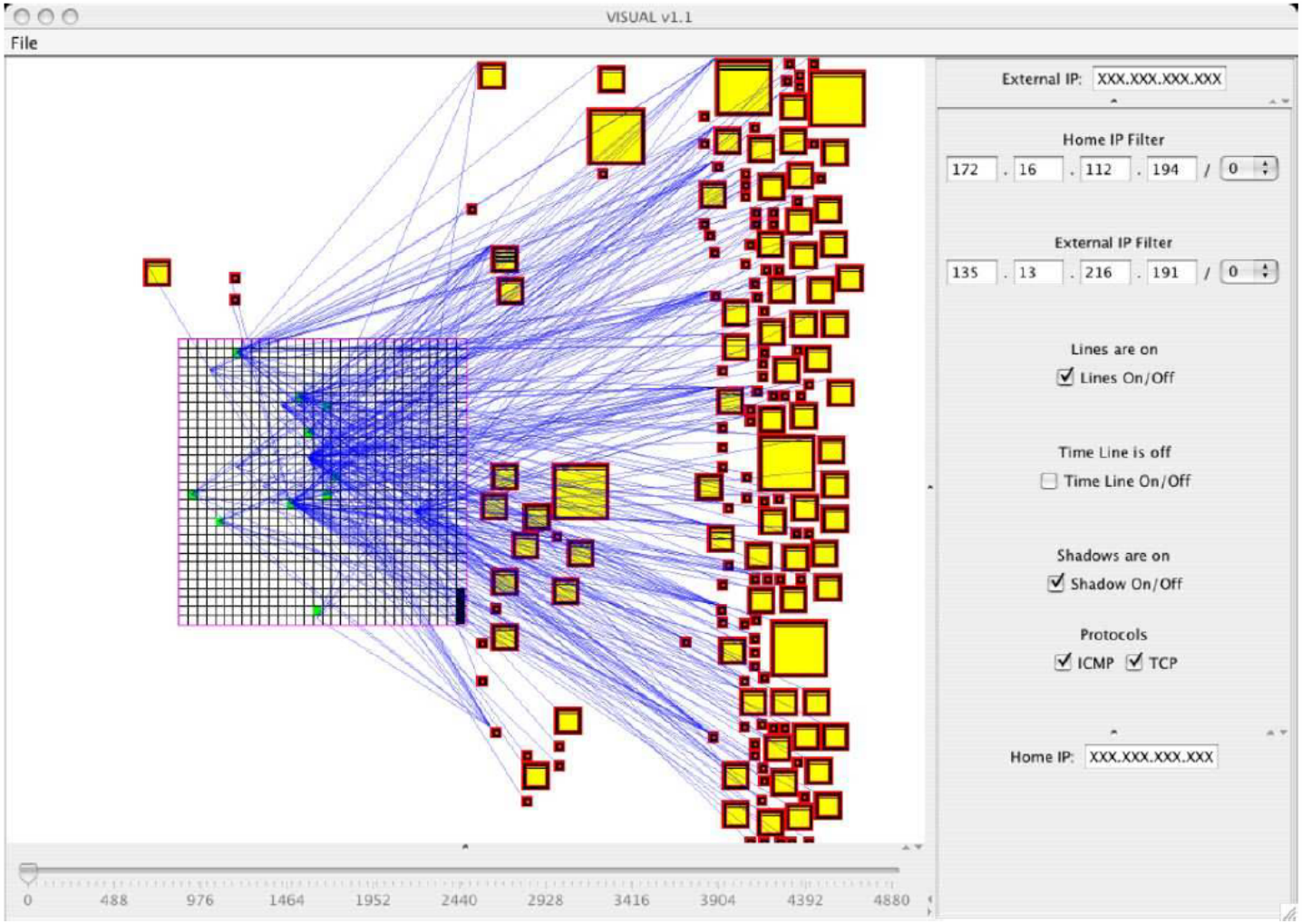

Figure : VISUAL (Ball et al., 2004)

Visual analytics for network security

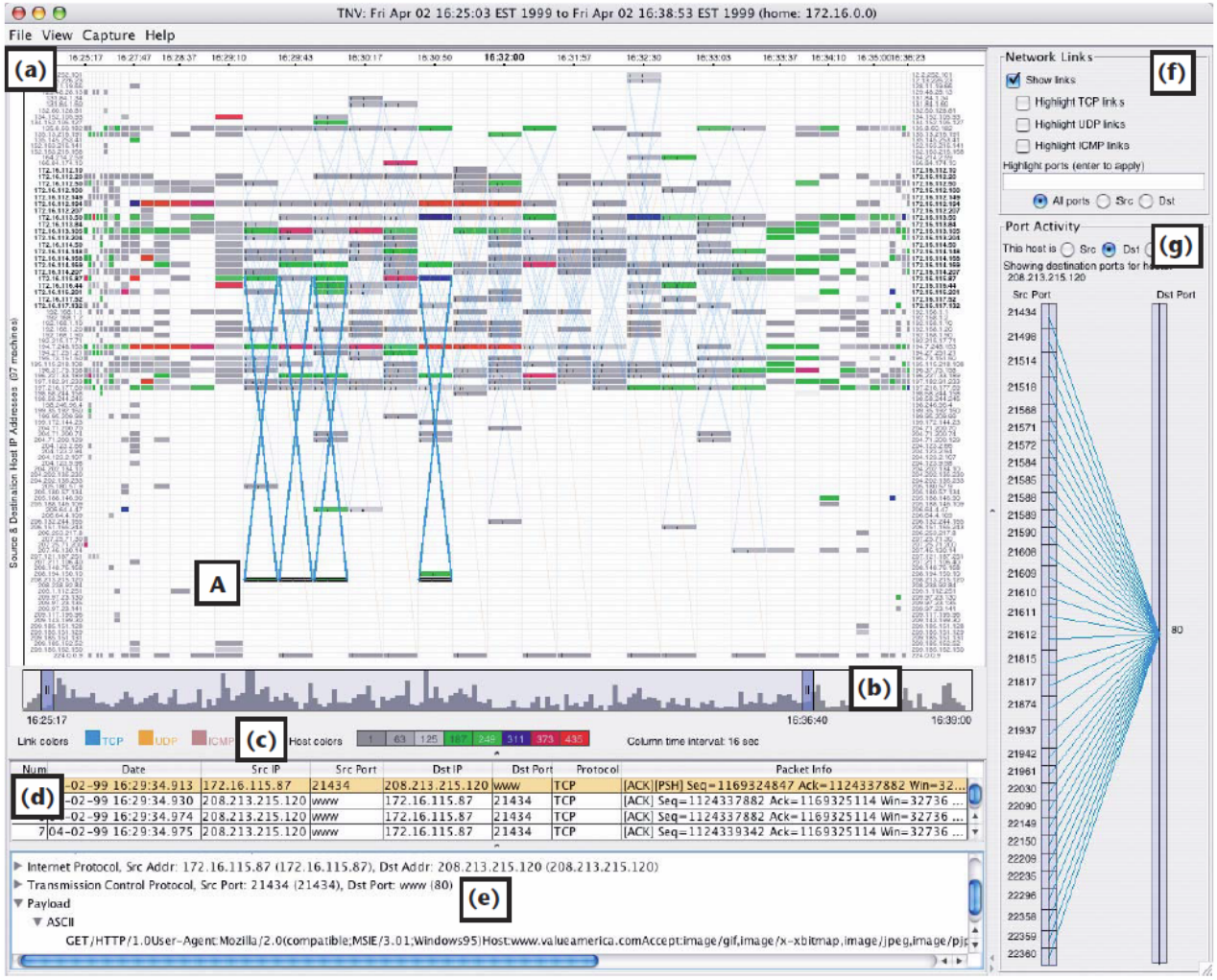

Figure : TNV (Goodall et al., 2006)

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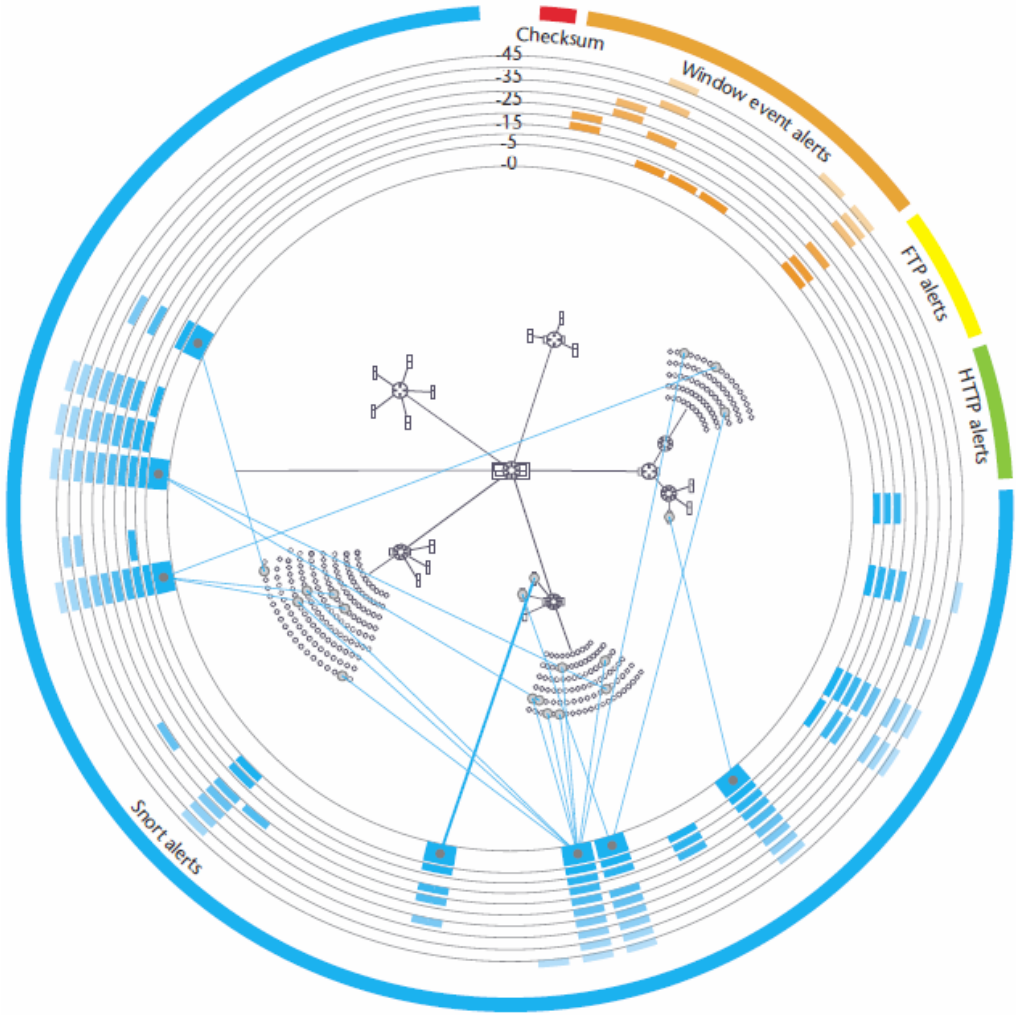


Figure : VisAlert (Foresti et al., 2006)

Visual analytics for network security

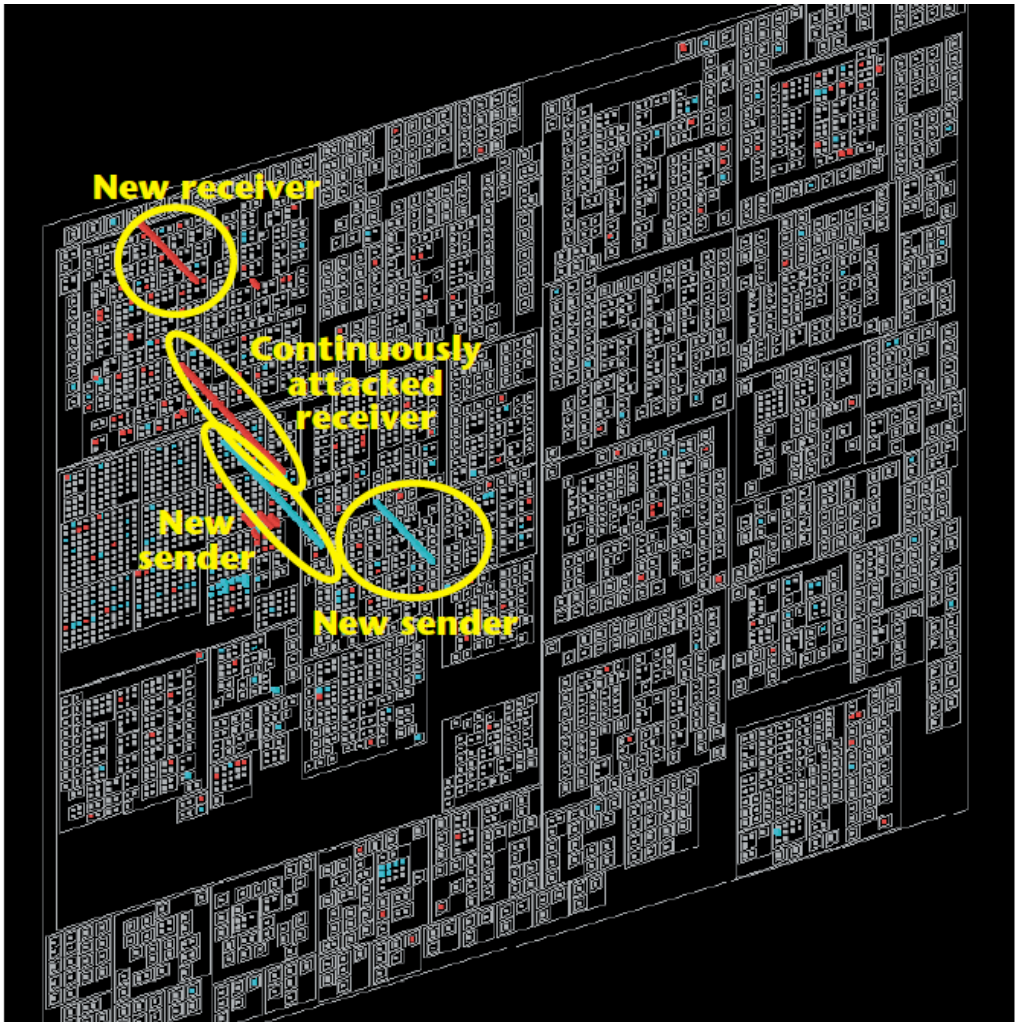


Figure : Itoh et al., (2006)

Visual analytics for network security

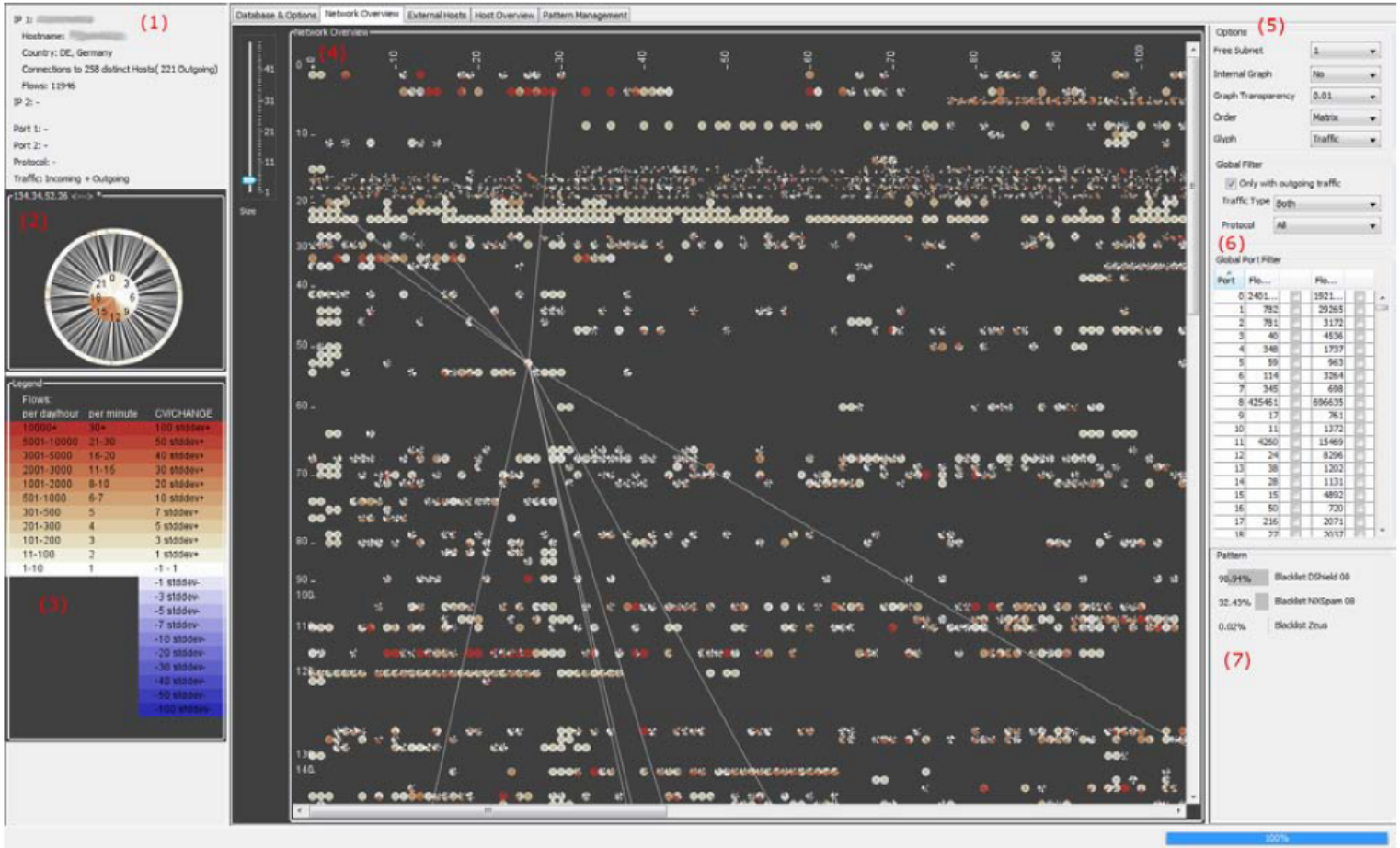


Figure : ClockView (Kintzel et al., 2011)

Visual analytics for network security

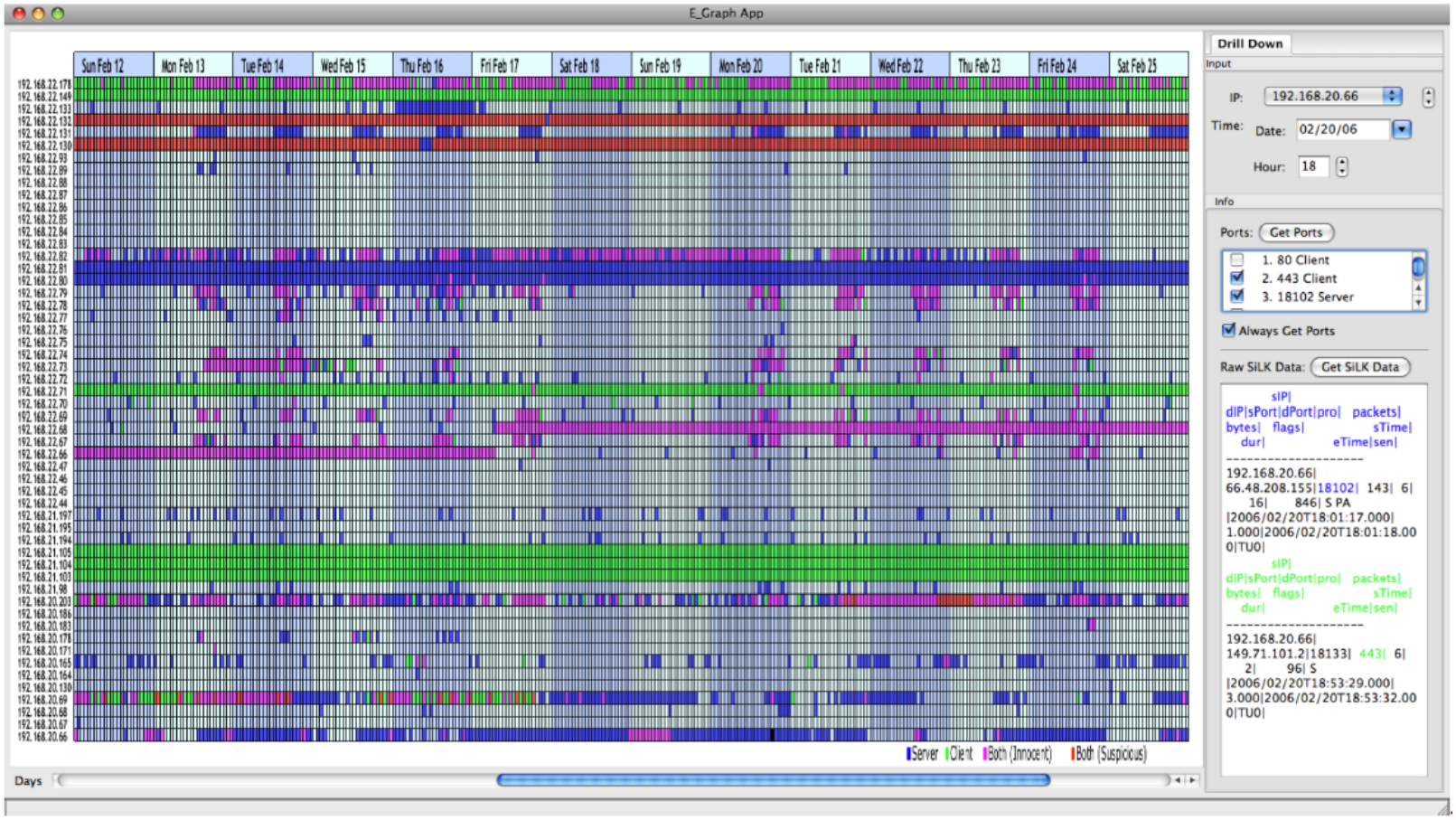


Figure : FloVis (Taylor et al., 2009)

Visual analytics for network security

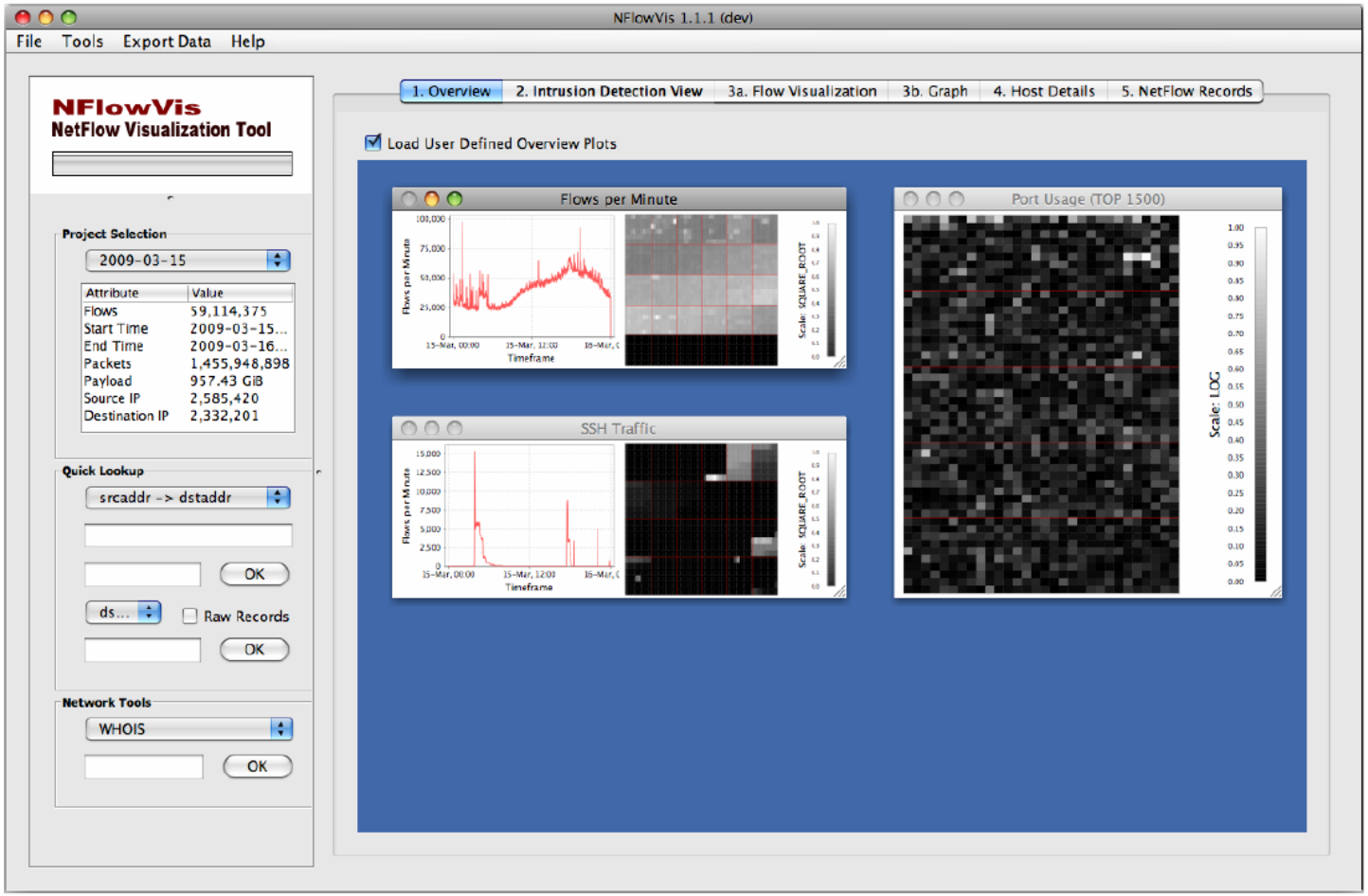


Figure : NFlowVis (Mansmann et al., 2009)

Visual analytics for network security

- Several common issues
  - Target fairly broad use cases
  - Lack design justifications
  - Don't necessarily meet user needs (match their work practices)

  "researchers come to us and say, here's a visualization tool, let's fit your problem to this tool. But what we need is a tool built to fit our problem" (Hao, VizSec 2013)
- Closest to our design are FlowVis and NFlowVis

Our approach

- Use case: detecting potential bandwidth depletion DDoS attacks
- Approach
  1. Started with a **low-fidelity design** of the proposed visual analytics tool based on existing design guidelines
  2. Selection of appropriate **time series visualisations** for tool by performing a quantitative graphical perception study
  3. Evaluation of the **proposed tool** by designing and conducting a mixed-method user study.

Our goal was to not only design a tool, but to do so via an effective user-centred design process

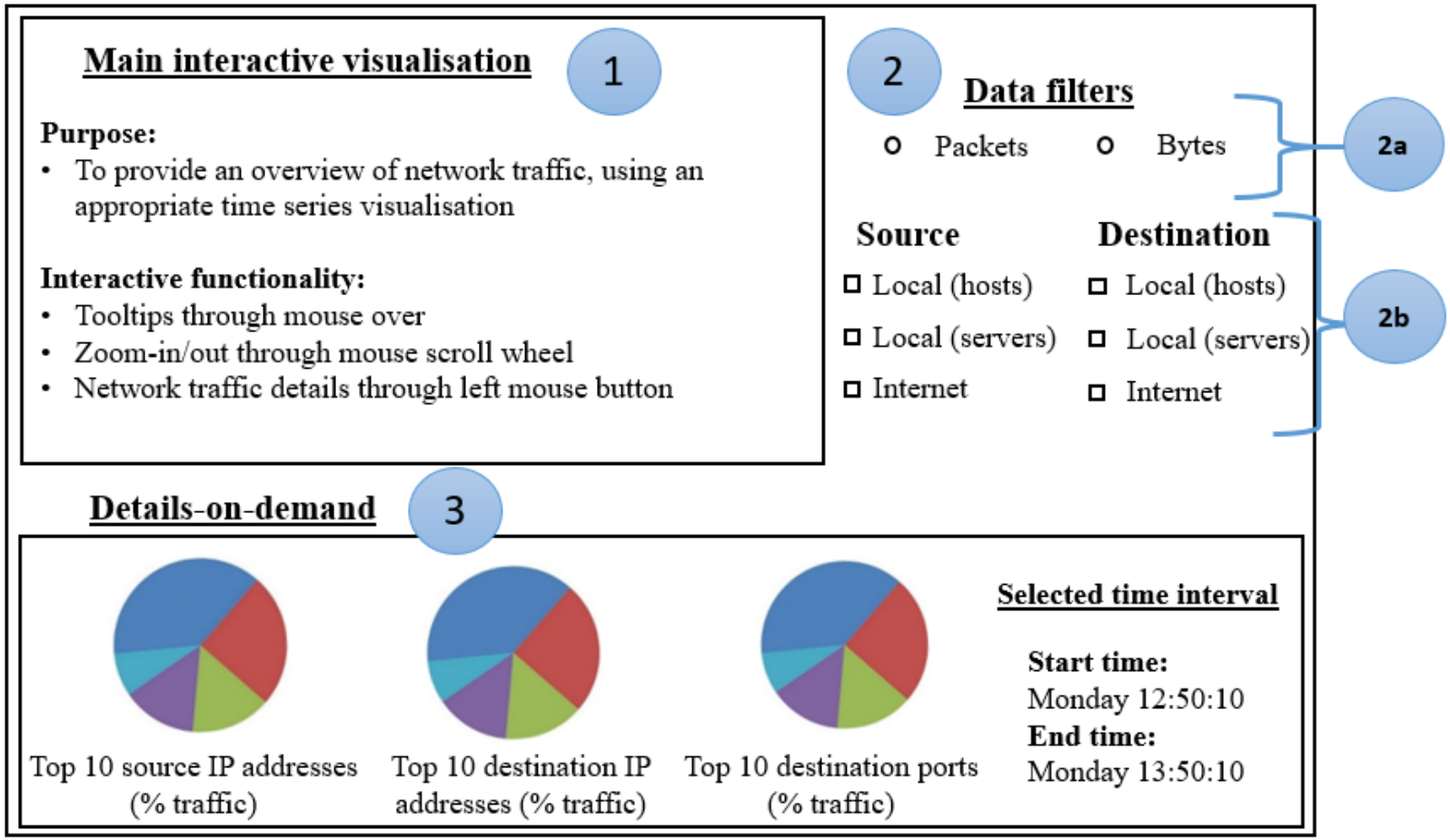
Talk Outline

1. Low-fidelity design
2. Time series visualisations
3. Proposed tool evaluation

Talk Outline

1. **Low-fidelity design**
2. Time series visualisations
3. Proposed tool evaluation

Initial low-fidelity design



1. Network traffic overview
2. Data filters (a) packets & bytes (b) source & destination
3. Network traffic details

Initial LF design approach

- Use case: detection of bandwidth depletion DDoS attacks from network flow data
- Pre-design domain analysis of use case identified following characteristics
  - Causes a considerable increase in the amount network traffic
  - Originates from multiple source IP addresses
  - Usually targets servers within a network
  - Usually targets well-known services/ports within a network (e.g., web and e-mail services)
- Shneiderman design: "Overview first, zoom and filter, then details-on-demand"
  - Hence, included options for tooltips and zoom

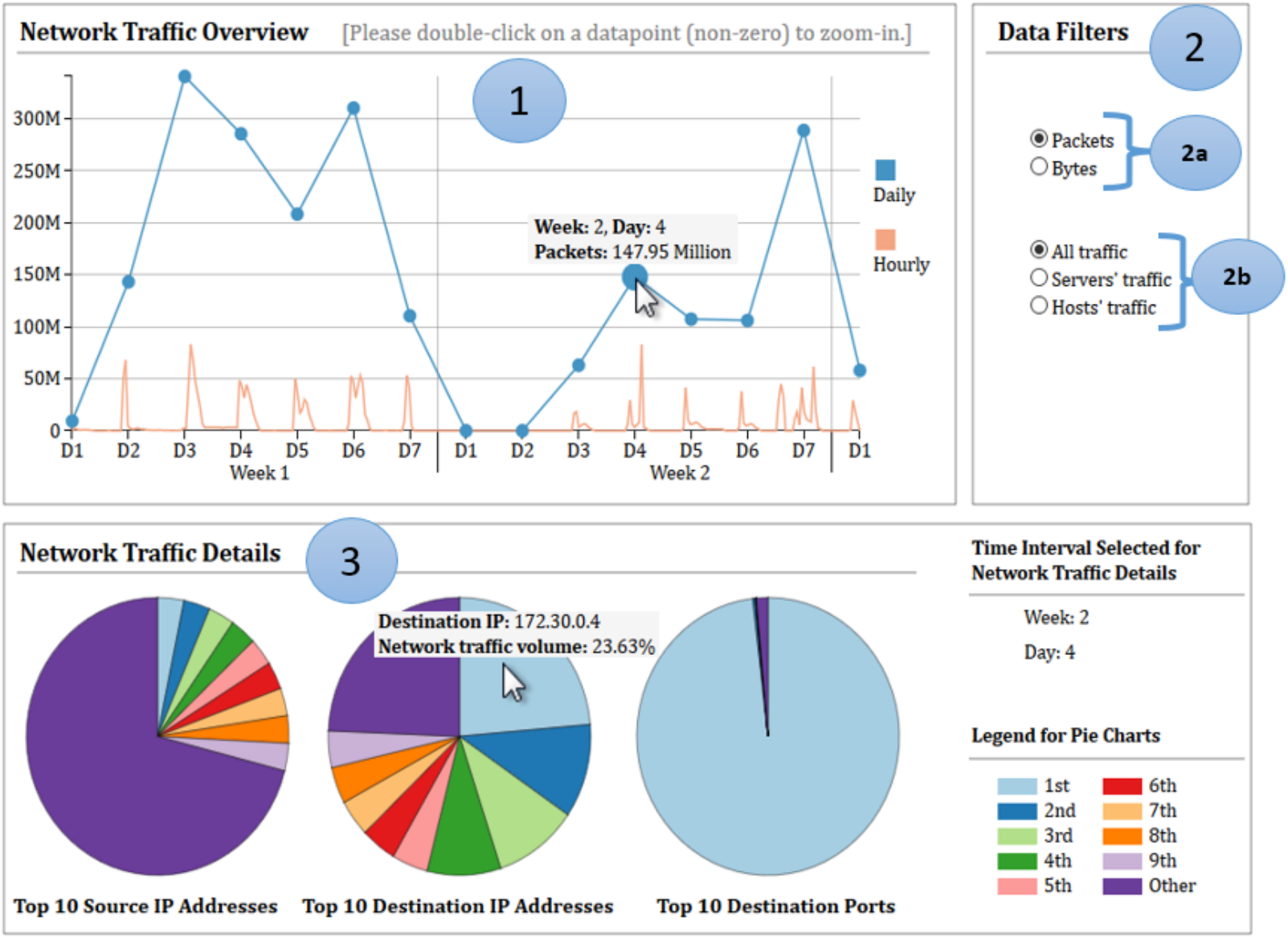
LF design validation

- Semi-structured design interviews with network security professsionals
- Asked about suitability of different components of proposed tool
- Interviews coded and analysed using the constant comparative method (CCM)
  - Part of grounded theory
- Categories
  - Core design elements
  - Interaction techniques
  - Titles and legends
  - Placement of interface components
  - Network traffic details
  - Network traffic overview

LF design validation (some results)

- Interaction techniques
  - Simplification of data filters
  - Endorsement of interaction techniques (e.g., tooltips, zoom)
- Increased specificity for titles
  - From ‘main interactive visualisation’ to ‘network traffic overview’
  - From ‘details on demand’ to ‘network traffic details’
- Inclusion of baseline historical data for network traffic overview

Proposed tool – A sneak peek



Talk Outline

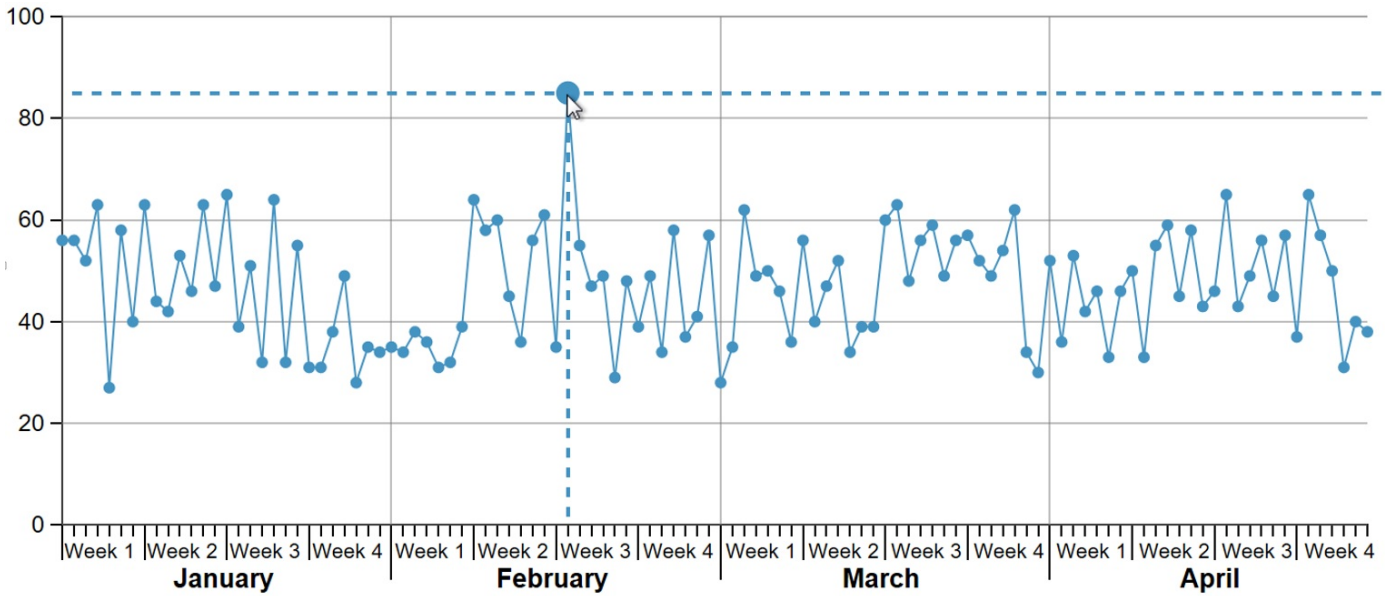
1. Low-fidelity design
2. **Time series visualisations**
3. Proposed tool evaluation

Time series visualisation component

- Initial plan: Determine appropriate time series visualisation based on feedback from LF designs
- In fact, we introduced 10 visualisations as part of our LF validation
  - Scatter plot, line chart, silhouette/area chart, bar chart, horizon graph, radar chart, rectangular heatmap, circular heatmap, treemap and sunburst visualisation
- However, feedback was not conclusive
- Further research uncovered gaps in the study of time series visualisations

Time series visualisations

- Time series visualisations widely used
- Example: Network security analysis
  - Time (horizontal), number of packets (vertical)



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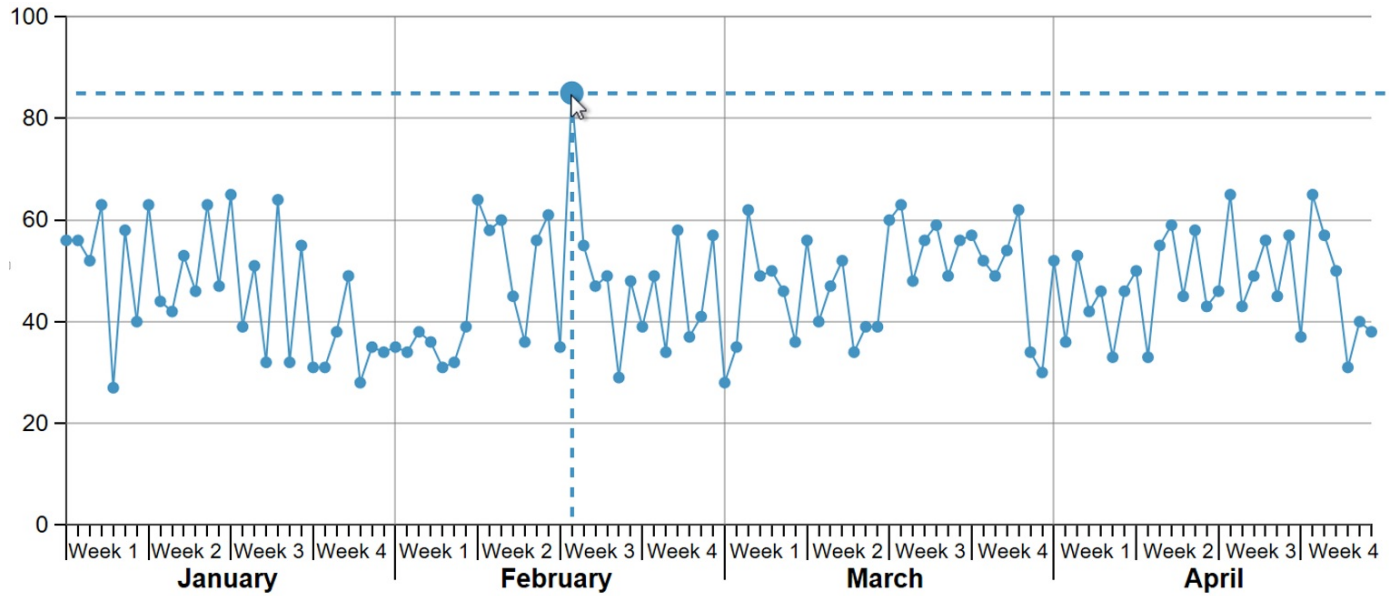

- Tasks such as maxima and comparison used to identify possible Denial of Service attacks

Time series visualisations

- Several possible visual representations to use

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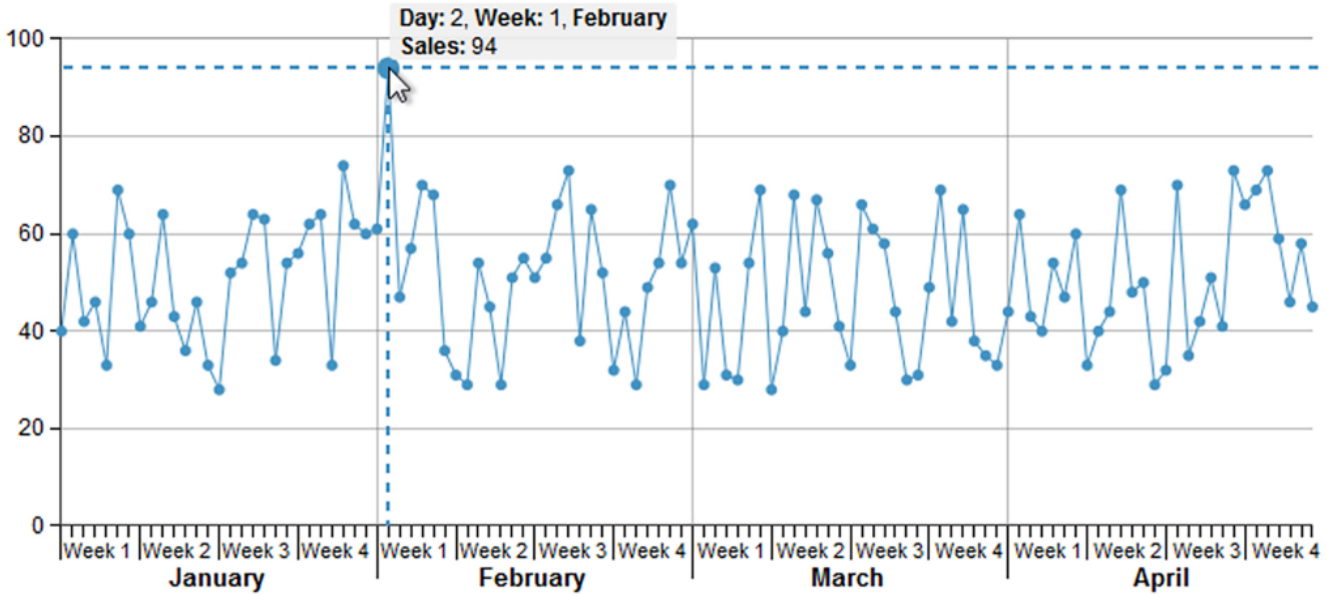
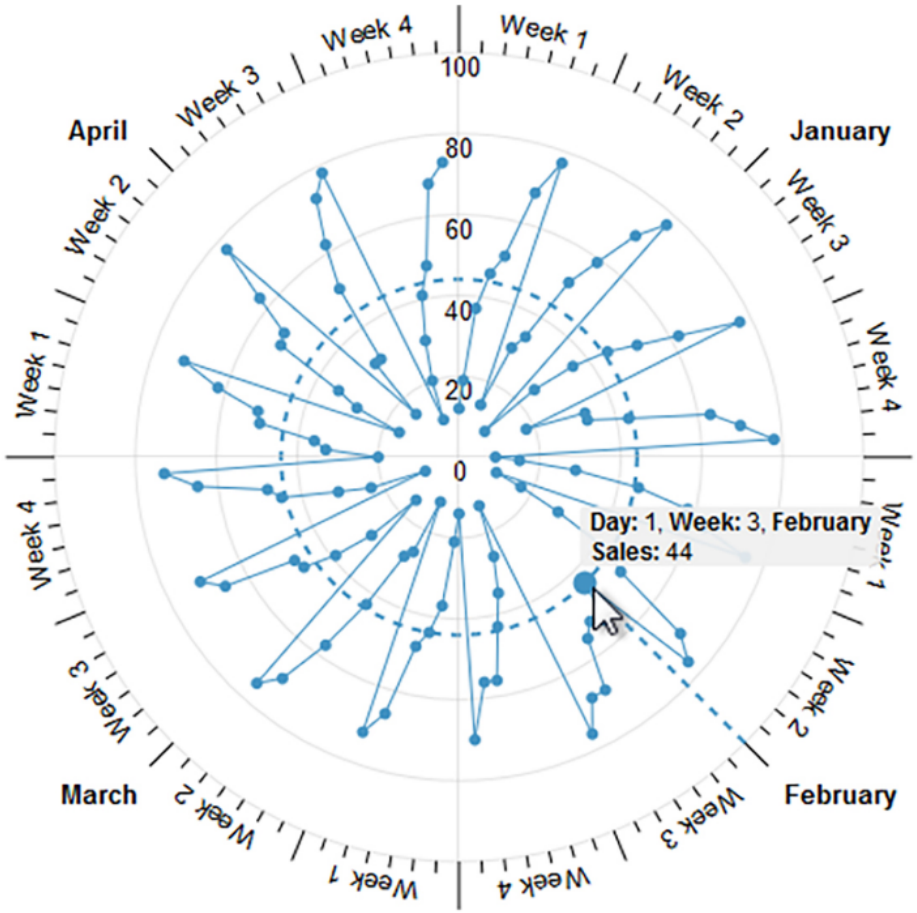


(a) Line chart

Time series visualisations

- Several possible visual representations to use



(b) Radar chart

Time series visualisations

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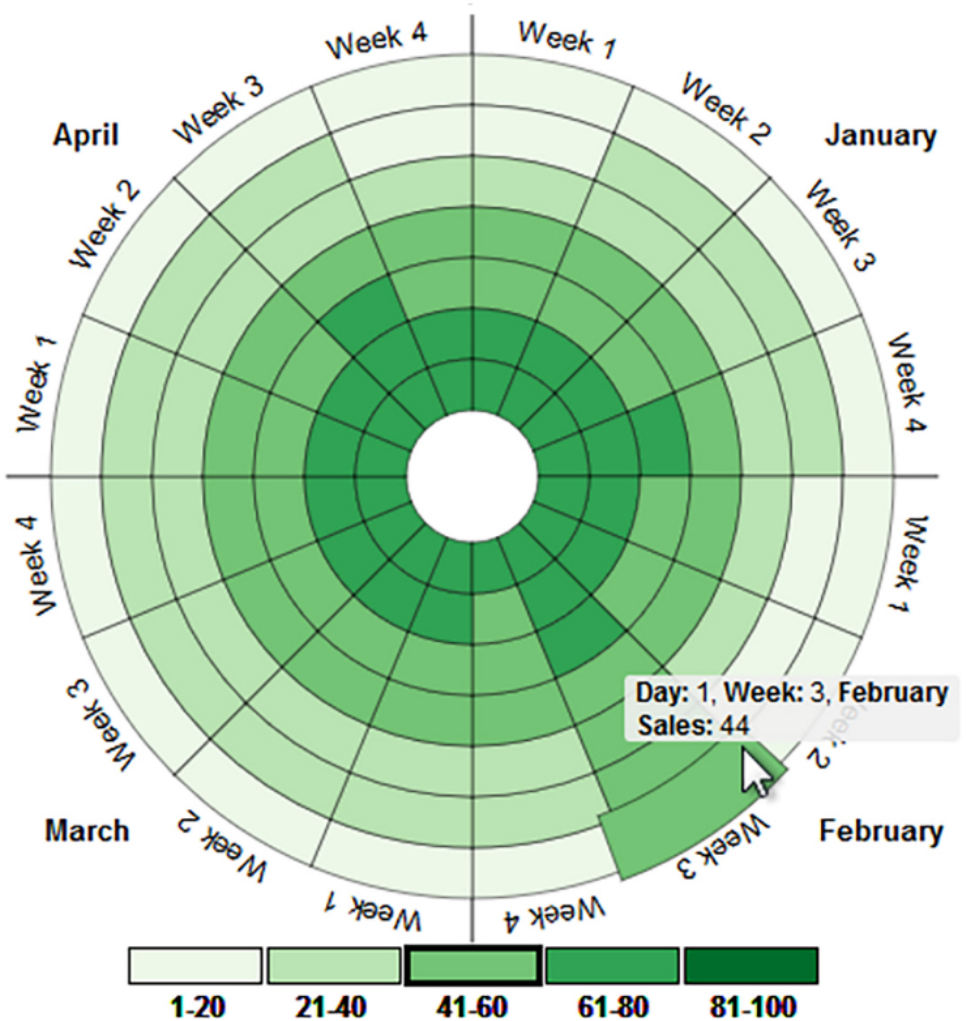

(d) Circular heatmap

Time series visualisations

- Which visual representation to use?

Time series visualisations

- Which visual representation to use?
- What about user interaction?

Time series visualisations

- Which visual representation to use?
- What about user interaction?
- Dozens of research papers since early 80s on visual representation and graphical perception
- Gaps re: some fundamental factors
  - Interaction techniques
  - Visual encodings
  - Coordinate systems

Gaps

Interaction techniques

Graphical perception studies commonly in **static setting**, limiting knowledge of **user experience**.

Gaps

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Visual encodings

Effectiveness within and across position and colour visual encodings, but **not area**.

Gaps

Interaction techniques

Graphical perception studies commonly in **static setting**, limiting knowledge of **user experience**.

Visual encodings

Effectiveness within and across position and colour visual encodings, but **not area**.

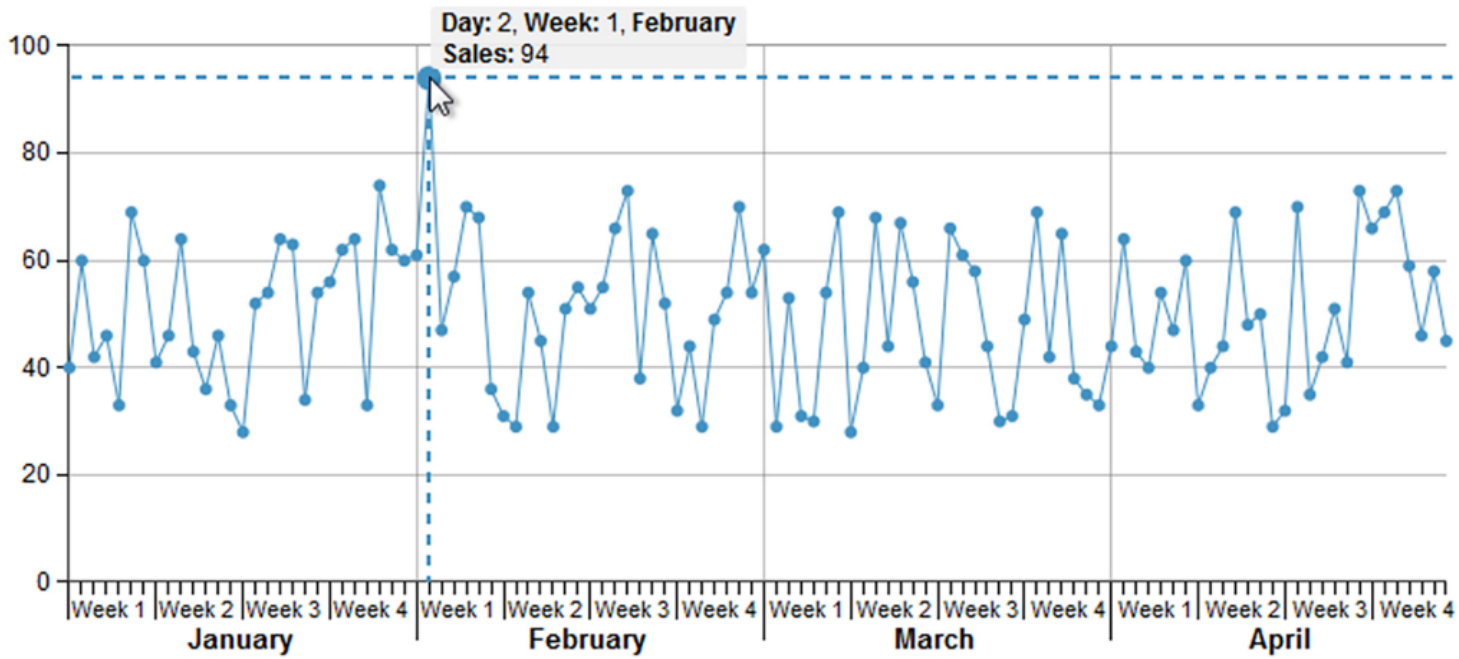
Coordinate systems

Limited empirical evidence on **Cartesian vs. Polar** coordinate systems for time series visualisations using different visual encodings.

Visual Representations

- Visual encodings: Position, colour, and area
- For each, a Cartesian and polar coord. system
- Interaction techniques: highlighting & tooltips

Position encoding: Cartesian (line chart)



(a) Line chart

Visual Representations

- Visual encodings: Position, colour, and area
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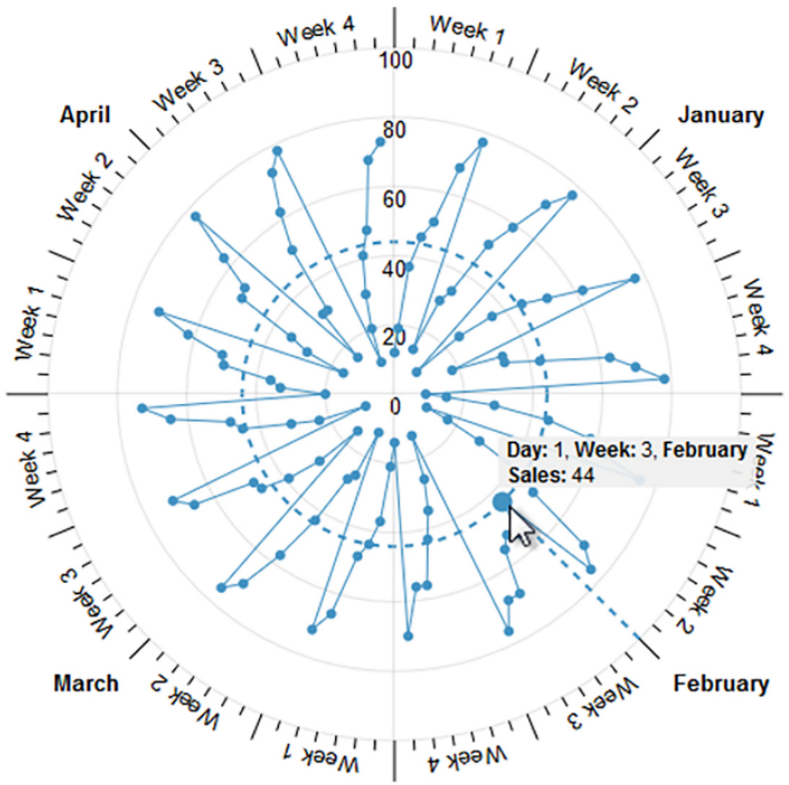
Position encoding: Polar (radar chart)

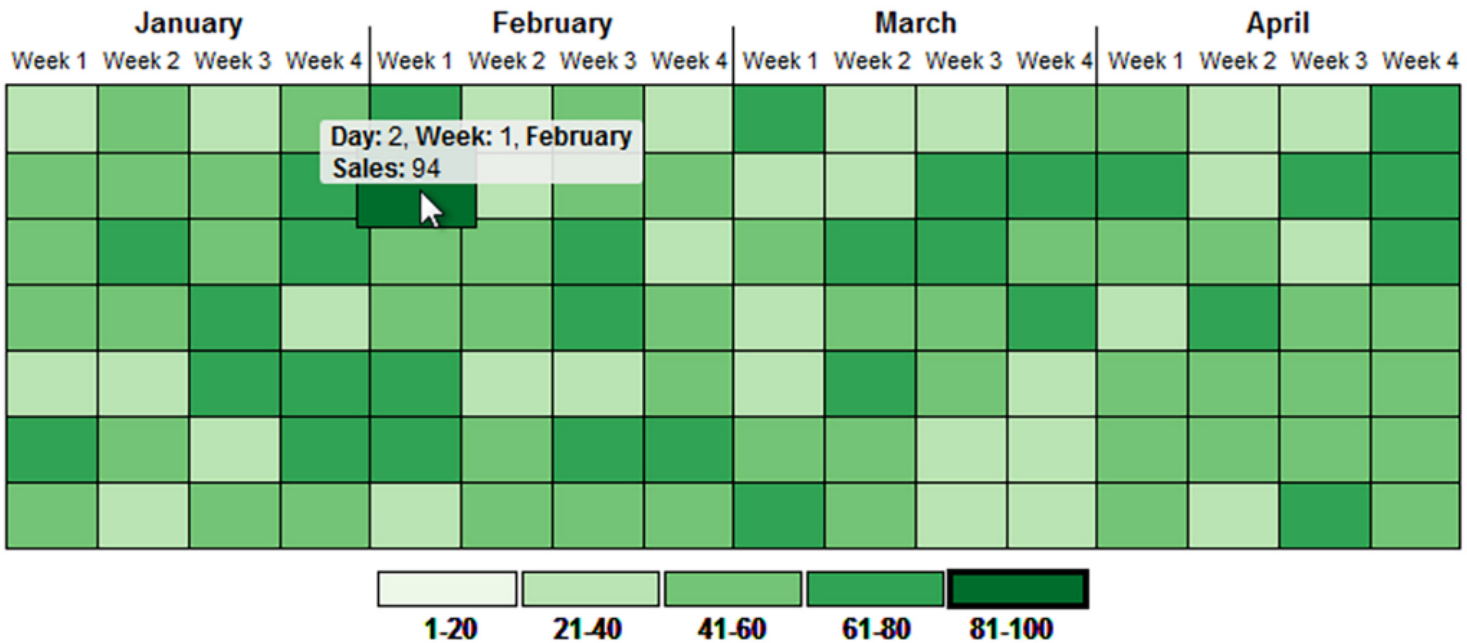


(b) Radar chart

Visual Representations

- Visual encodings: Position, colour, and area
- For each, a Cartesian and polar coord. system
- Interaction techniques: highlighting & tooltips

Colour encoding: Cartesian (rectangular heatmap)



(c) Rectangular heatmap

Visual Representations

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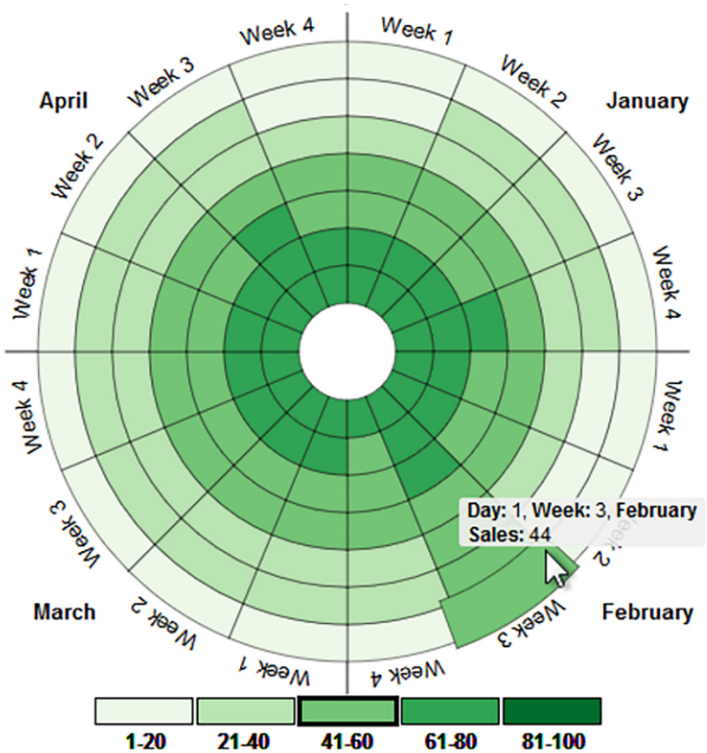
- Interaction techniques: highlighting & tooltips

Colour encoding: Polar (circular heatmap)



(d) Circular heatmap

Visual Representations

- Visual encodings: Position, colour, and area
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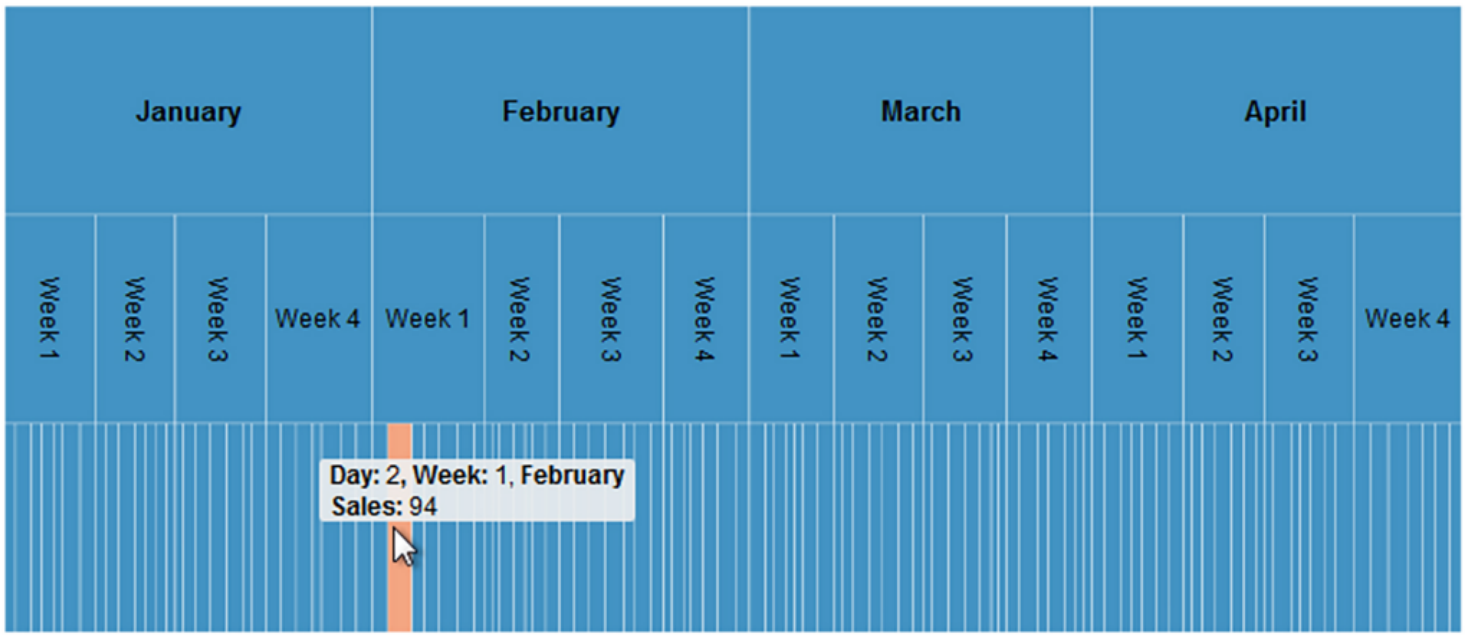
- Interaction techniques: highlighting & tooltips

Area encoding: Cartesian (icicle plot)

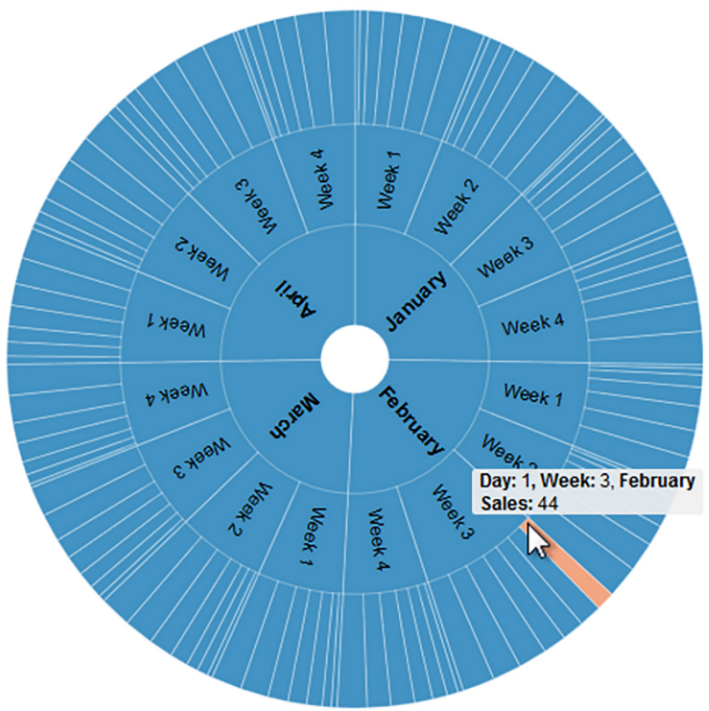


(e) Icicle plot

Visual Representations

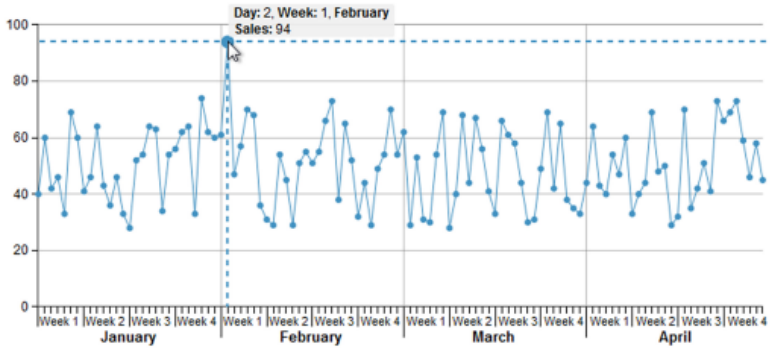
- Visual encodings: Position, colour, and area
- For each, a Cartesian and polar coord. system
- Interaction techniques: highlighting & tooltips

Area encoding: Polar (sunburst plot)



(f) Sunburst visualisation

Visual Representation Summary



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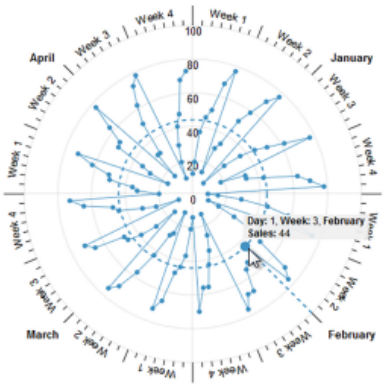
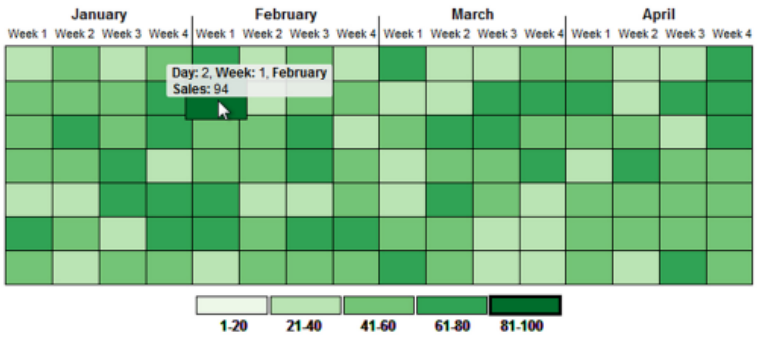


(b) Radar chart



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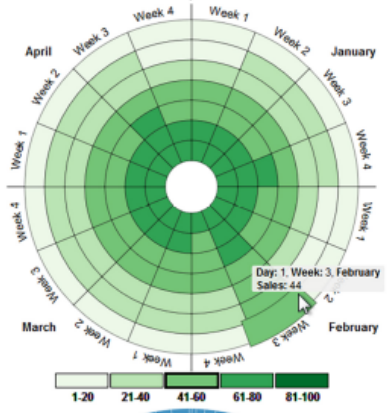

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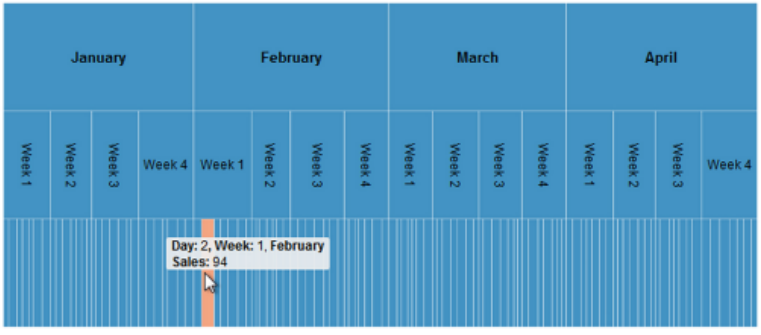
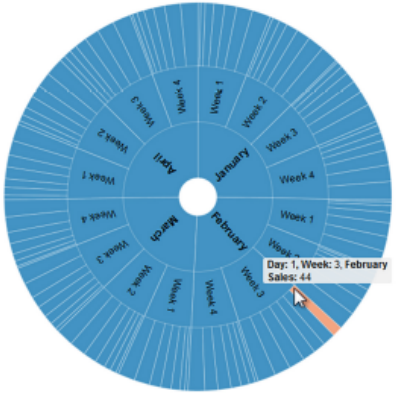


(e) Icicle plot



(f) Sunburst visualisation

Graphical perception study

- Graphical perception study

Graphical perception study

- Graphical perception study
  - 4 arrangements of two **interaction techniques**:

    No interaction Only tooltips
    Only highlighting Both highlighting & tooltips

  - 3 **visual encodings**:

    Position Colour Area

  - 2 **coordinate systems**:

    Cartesian Polar

  - 4 **study tasks**:

    Maxima Comparison
    Minima Trend detection

- 96 (4x3x2x4) experimental conditions

Study Tasks

- Maxima
  - To identify the highest absolute value in a dataset
- Minima
  - To identify the lowest absolute value in a dataset
- Comparison
  - To compare two sets of data points to find out which set has the highest aggregated value
- Trend detection
  - To identify subset of data (i.e., a week) with lowest value increase (upward trend) within dataset

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Task scenario

Presented as sales data of a fictitious company

Study Design

- Study design
  - 24 study participants
    (14 male, 10 female; 18-44 years old)
  - Within-subject factorial design with 96 (4x3x2x4) experimental conditions for each participant
- Experimental conditions
  - Counterbalanced visualisations and interactions
  - Tasks ordered simple to complex
    (Javed et al., 2010)
- Data for visual representations
  - 96 distinct, synthetic time series datasets (one for each condition) following Fuchs et al. (2013)
  - Each dataset had 112 data points (1 per day) over 16 week period

Study Procedure

Stage	**Description**
Introduction	Greetings, consent, demographic questionnaire, study explanation
Maxima	Task training, 24 conditions
Minima	Task training, 24 conditions
Comparison	Task training, 24 conditions
Trend detect.	Task training, 24 conditions

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24 experimental conditions for each task
(3 visual encodings x 2 coord. systems x 4 interact.)

Study data collected

Effectiveness measured with four components, collected after each experimental condition

Study data collected

Effectiveness measured with four components, collected after each experimental condition

- Completion of an experimental condition (sec)
- Accuracy of the given answer (binary)
- Confidence of the given answer (5-point Likert)
- Ease of use of a visualisation (5-point Likert)

Final two collected via questionnaire per condition

Results: Interaction Techniques

- Interactivity enhanced user experience
  - Interaction significantly better than no interaction
  - Confidence and ease-of-use
  - No affect on completion time or accuracy

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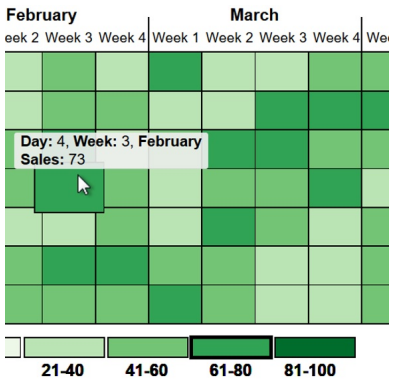

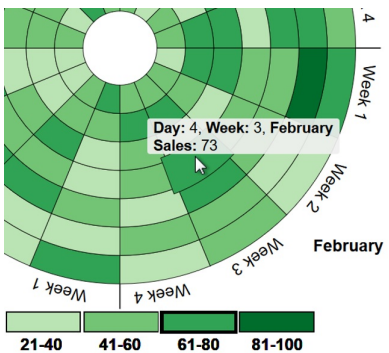

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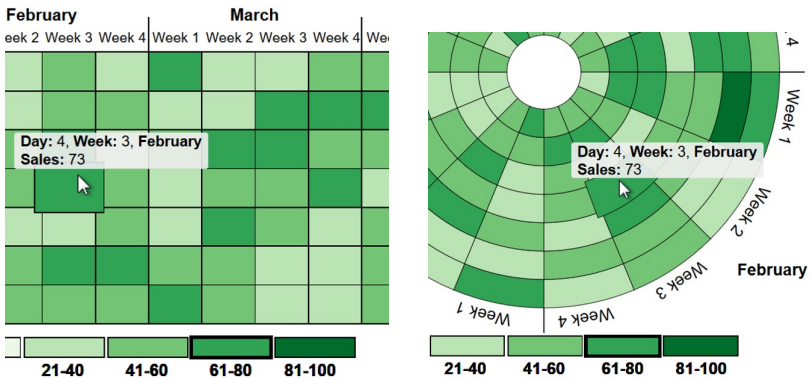

- Textual (tooltips) better than highlighting

Results: Visual Encodings

- Completion, accuracy, confidence, & ease

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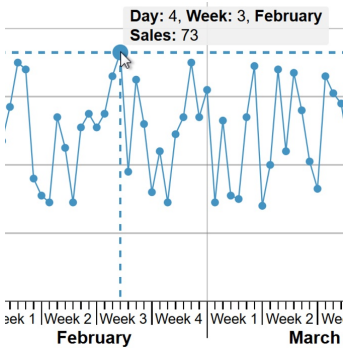
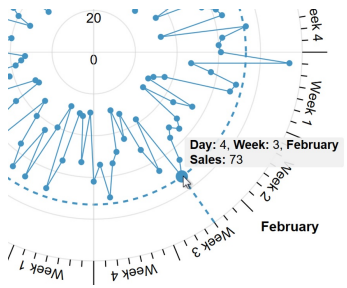
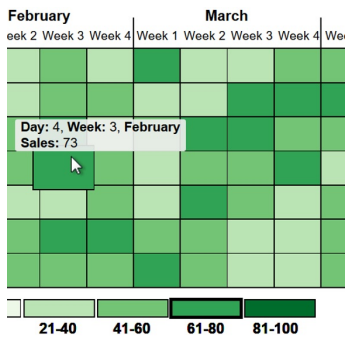
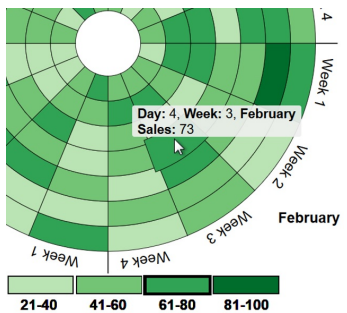
- Completion, accuracy, confidence, & ease
- Position & colour better: max, min, trend det.
  - Colour more accurate for minima









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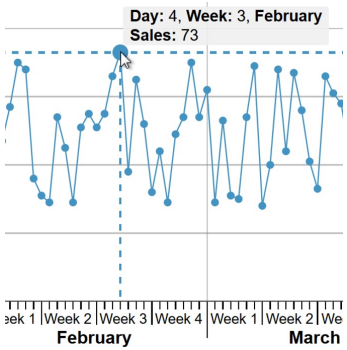
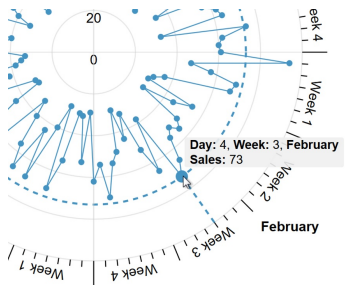
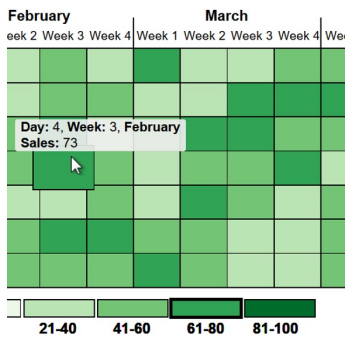
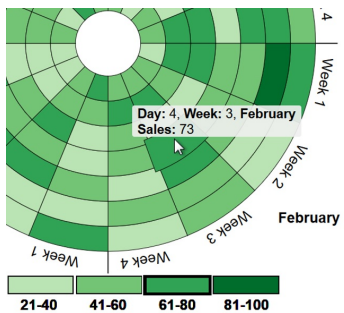
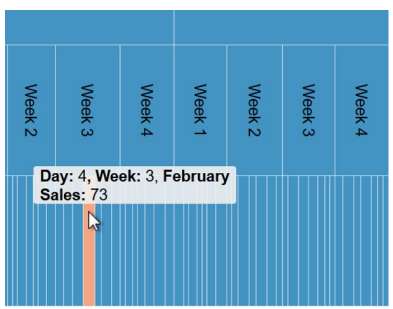


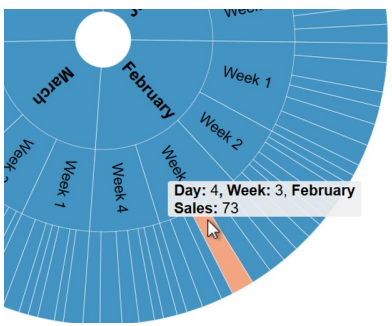






- Area more effective for comparison task





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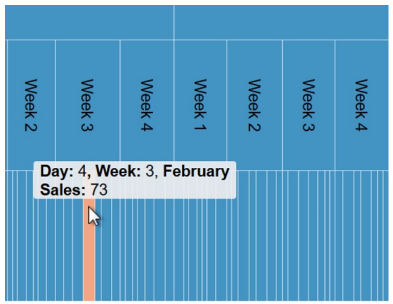

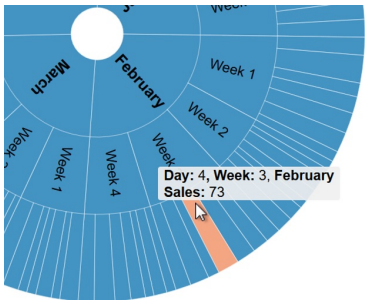

Results: Coordinate Systems

- Completion, accuracy, confidence, & ease
- Cartesian generally better than polar
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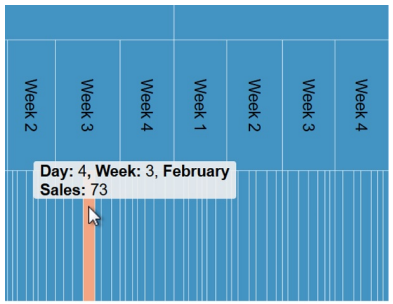
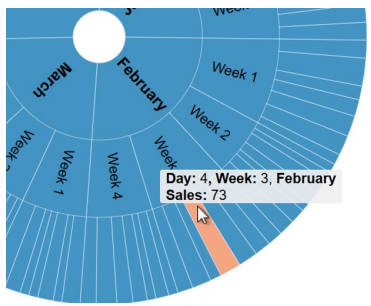
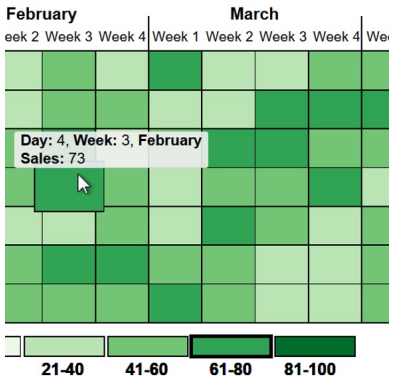
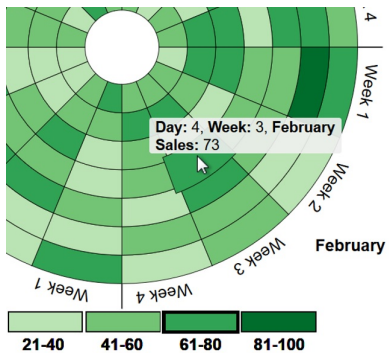




- Neglible effect of coordinate system for colour





Key Findings

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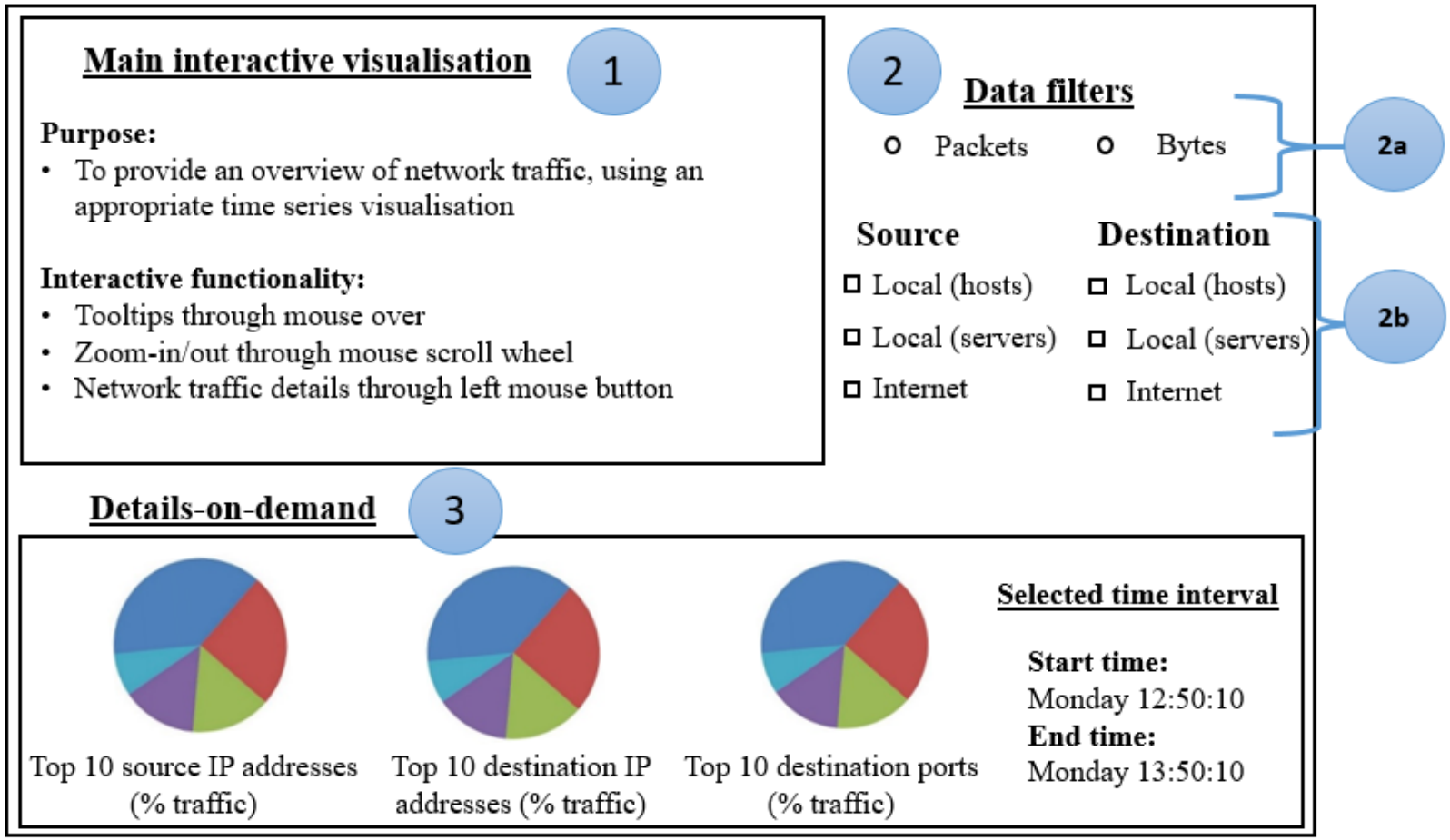
Key Findings

- Interactivity improved user experience
  - Improved confidence and ease of use, without a significant decrease in completion time or accuracy.
- No “one-size-fits-all”
  - The choice of a visual representation should be based on the type of tasks
- Generally, Cartesian is better
  - Cartesian coordinate systems are generally comparable or more effective than Polar, except for visualisations that use area for minima.

Talk Outline

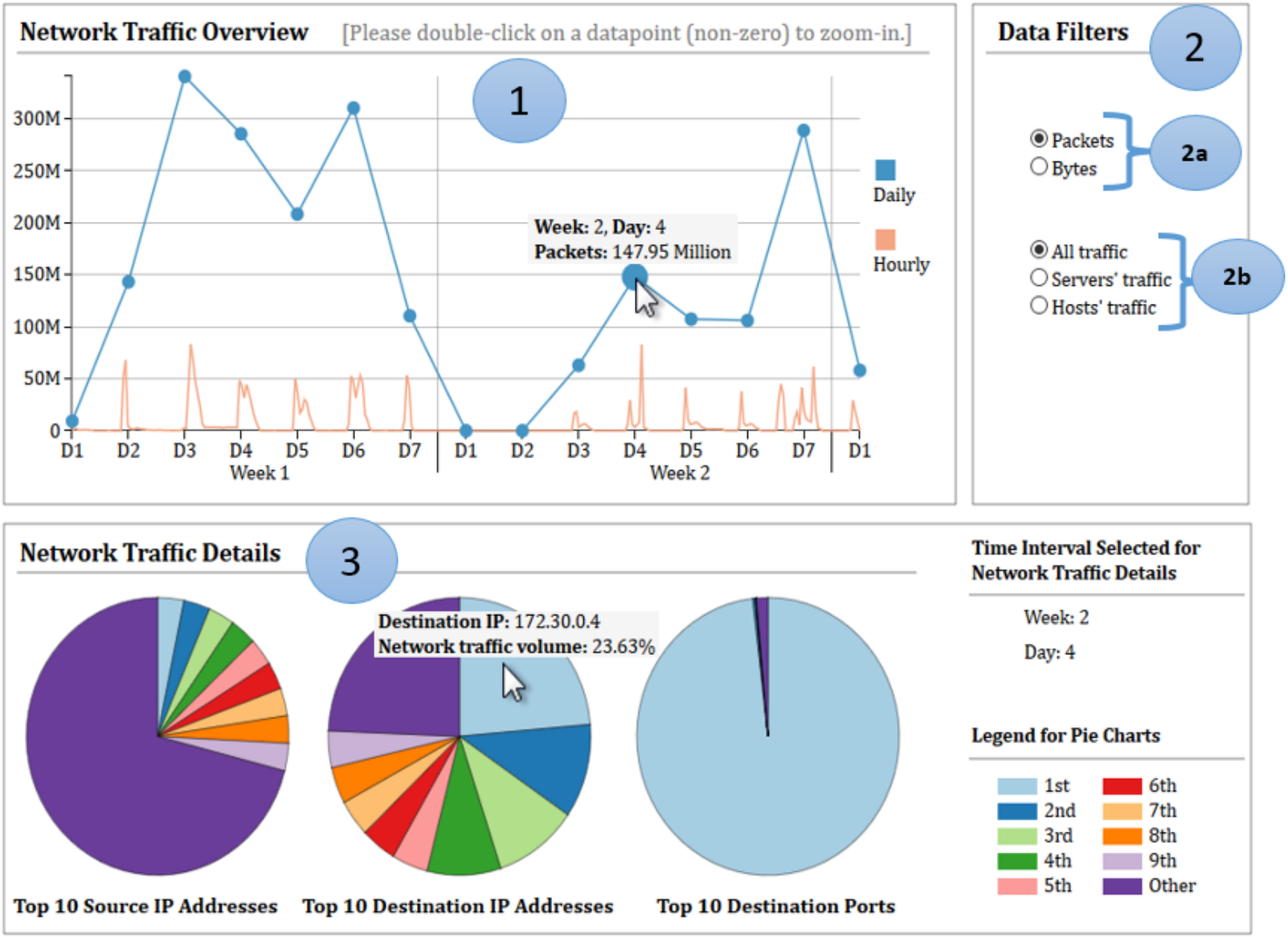
1. Low-fidelity design
2. Time series visualisations
3. **Proposed tool evaluation**

Initial low-fidelity design (reminder)

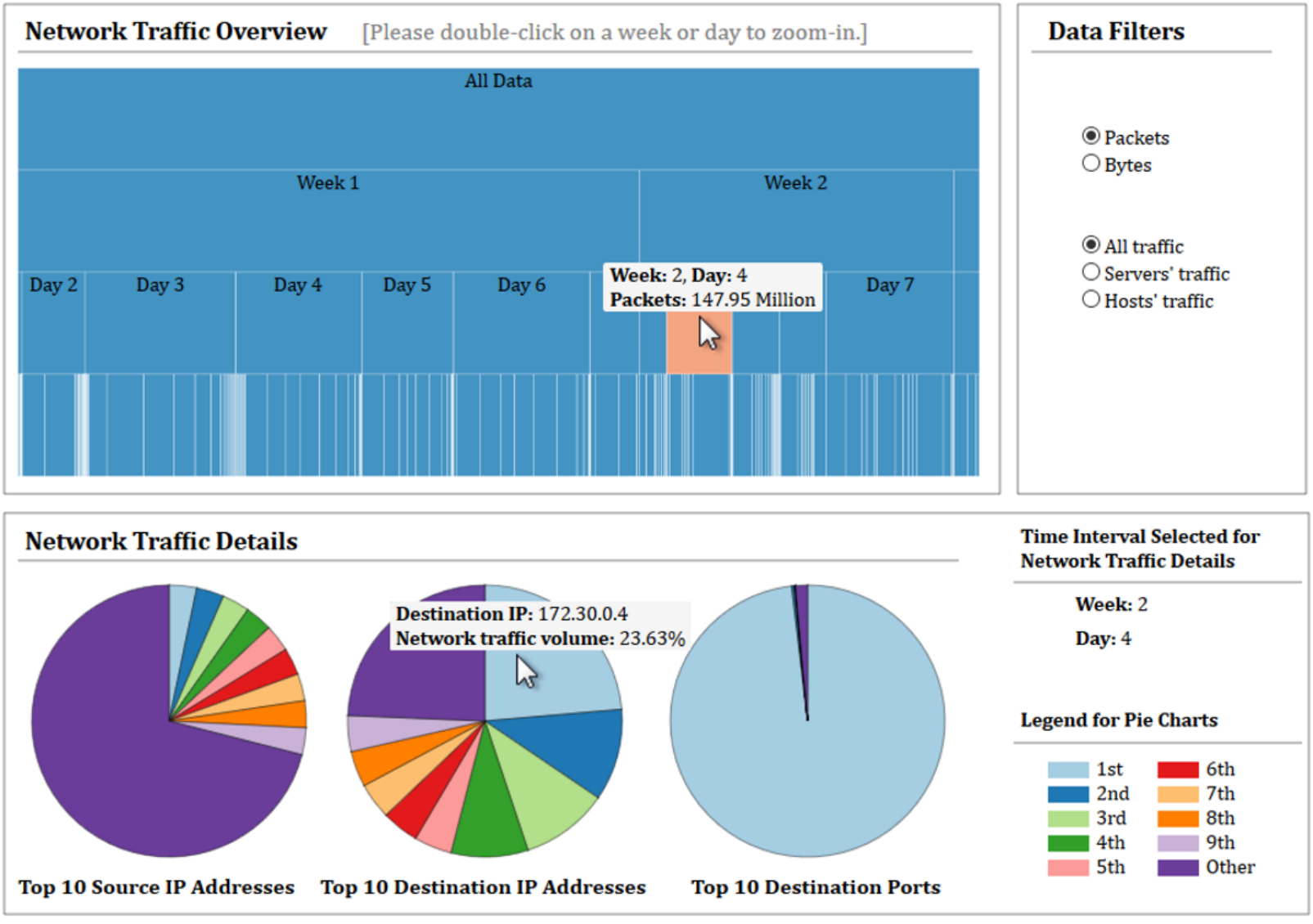


1. Network traffic overview
2. Data filters (a) packets & bytes (b) source & destination
3. Network traffic details

Proposed tool – Line chart



Proposed tool – Icicle plot



Proposed tool – Updates

- Streamline of source and destination filters
  - And radio buttons, rather than checkboxes
- Updates to some titles
- Inclusion of zoom interaction
- Visualsation choices
  - Line chart: Effectiveness for maxima, minima, and trend detection
    (could have also selected rectangular heatmap)
  - Icicle plot: Effectiveness for data comparison
    (could have also selected sunburst visualisation)

Tool Development and Dataset

- Developed as a web application
  - HTML5, CSS, Javascript, and D3.js
  - MySQL to store network flow data, via PHP
- Network flow dataset from the VAST 2013 challenge
  - 8GB of data with about 70mil network flow records
  - 15 days of network traffic collected from a simulated network
  - Includes four potential bandwidth depletion DDoS attacks
- We created three different variations of the dataset for our three experimental conditions
  - Original & increased/decreased traffic volume
  - Temporal position of DDoS attacks randomly positioned

User Study

- We recruited 12 participants for a lab study to measure the tool's effectiveness
- A within-subjects design with participants exposed to three conditions (counterbalanced)
  1. Tool with line chart only
  2. Tool with icicle plot only
  3. Tool with both visualisations available (radio button)
- Participants asked to find three possible network attacks
- Measures
  - Completion time and accuracy
  - Usability measure using SUS and NASA-TLX
  - Also conducted a post-evaluation design interview

Quantitative Results

Conditions	Time(s)	Acc.(%)	SUS	NASA-TLX
Line	153	89	77	31
Icicle	129	89	76	31
Both	164	97	80	31
Average	149	92	78	31

- No statistically significant difference between the conditions

Qualitative Results

- Post-evaluation semi-structured design interview
- Interviews recorded and analysed similar to LF design
- Network traffic overview
  - Preference for line chart vs. icicle
  - Desire for ability to better compare data, e.g., view zoomed chart simultaneously with original
- Network traffic details
  - Desire for more detail and interaction
- Interactive functionality
  - Desire for more detail with tooltips

Looking Ahead

- Future work on time series visualisations
  - Increased study of interactivity
  - Offset, interaction effects, different tasks and interactions
  - Use in different domains
- Visualisations for network security
  - Challenge to meet needs/desires of network security professionals
  - Challenge to convey information in visualisations. Max/min are "easy". Comparison and trend detection more challenging.
  - Approaches need to start with clear use case, and requirements (e.g., involvement of end-user professionals)

Further reading

Work on time series visualisations was published at CHI'16. Paper available from my website.

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