Chapter 7
Guiding the Selection of Visualization Techniques

> Today we live in an information-based technological world. The problem is that this is an invisible technology. Knowledge and information are invisible. They have no natural form. It is up to the conveyor of the information and knowledge to provide shape, substance, and organization [...]
>
> Norman (1993, p. 104)

So far, this book approached the visualization of time-oriented data from a conceptual perspective. We looked at the characteristics of time and time-oriented data, considered aspects of visualization design, and learned how interaction and analysis methods can be employed to enhance the visualization. In this chapter, we switch to a more practically oriented perspective and address the question of how to select visualization techniques that are appropriate for an application problem at hand.

Such a practical perspective is immensely important because searching for suitable visualization techniques for time-oriented data can be a daunting tasks. There are so many options and so many solutions to be found in so many scientific publications, books, and online resources that it is hardly possible to check them all. With the examples of visualization techniques included in the previous chapters, we just scratched the surface of a rich body of existing work. In fact, there is an abundance of valuable techniques and tools. So, a person who has some time-oriented data to be visualized does not really know where to start and where to end. This calls for mechanisms to support researchers and practitioners in finding suitable techniques that fit their needs. This chapter describes how this call can be answered.

7.1 Structuring the Space of Solutions

When it comes to searching a large space, in our case the space of visualization techniques, it is very helpful to have a structure that helps us reduce the complexity of the search. Much like in *divide & conquer* approaches, we want to have a structure

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that subdivides the space into smaller partitions. Our search can then focus on relevant subspaces while ignoring the ones that are not of interest for a particular application problem.

The conceptual considerations from the earlier chapters of this book are promising starting points for finding such a structure. In particular, we looked at three key questions: What is visualized, why is it visualized, and how is it visualized? These three questions relate to the different characteristics of time and time-oriented data (what), the different analytical tasks one seeks to solve (why), and the different options for designing the visual representation (how). Yet, while the discussion of these relevant aspects provides us with valuable information, the involved details can be a too big hurdle for an easy entry into the field. For example, people who do not regularly work with visualization or other data analysis tools might not be able to fully grasp the diversity of aspects to be considered.

Thus, it makes sense to insert a new simpler layer of abstraction. This new layer should focus on aspects that are easy to decide, while leaving aspects being more subtle for later inclusion. Moreover, the simpler layer should focus on those aspects that are typically addressed by current visualization techniques. Therefore, we now consider only three key criteria: (1) time and (2) data, the what, and (3) visual representation, the how, while neglecting the why aspect. Each key criterion has two sub-criteria with two corresponding categories each, which gives us a much simpler overall structure compared to the full theoretical categorization from Chapter 4. The simplified schema is now more suitable for practical use:

- **Time**
  - *Primitives* – points vs. intervals
  - *Arrangement* – linear vs. cyclic
- **Data**
  - *Number of variables* – single vs. multiple
  - *Frame of reference* – abstract vs. spatial
- **Visual representation**
  - *Mapping of time* – static vs. dynamic
  - *Dimensionality* – 2D vs. 3D

The time and data criteria pick up four selected aspects (i.e., type of time primitives, arrangement of time, number of variables, and frame of reference) from Chapter 3, while the visual representation criterion refers to two aspects (i.e., mapping of time and dimensionality) discussed in Section 3.2. As such, this simplified categorization schema concentrates on aspects that are relatively easy to decide. For example, if data are abstract or have a spatial frame of reference is clear from the description of the data. If a visualization is 2D or 3D is also obvious and hence easy to categorize. On the other hand, the new schema does not include the analysis tasks, that is, the why aspect. There are two reasons for that. First, for many applications, there is not just one task to be tackled. Instead, tasks may be constantly in flux where working on one task naturally leads to other tasks. Moreover, deciding whether a particular visualization technique is suitable for solving a certain task is not easy. In fact, objective assessments of task suitability are rarely reported in the literature, and if so, mostly at the level of the visual encoding only (as we did for color-coding in Section 4.2.2), but not at the level of visualization techniques.

But still, even without the task level, we now have a simplified categorization schema that allows us to subdivide the space of solutions into smaller subspaces to restrict the search for suitable visualization techniques. How the search can actually be carried out will be described next.

7.2 The TimeViz Browser

As we said before, the problem is to find visualization techniques that match a user's particular needs. A tool that can help mitigate this problem is the *TimeViz Browser*. Designed as an interactive website, the TimeViz Browser enables practitioners and researchers to explore, investigate, and compare visualization techniques for time-oriented data. The key advantages of the TimeViz Browser are threefold. First, it brings together in a single place the available visualization techniques, which are otherwise scattered across a variety of sources. Second, it employs the simplified categorization schema to tag and structure the available techniques, which makes it easier to interactively explore the space of solutions. And third, the TimeViz Browser is freely available at https://browser.timeviz.net so that anyone can use it.

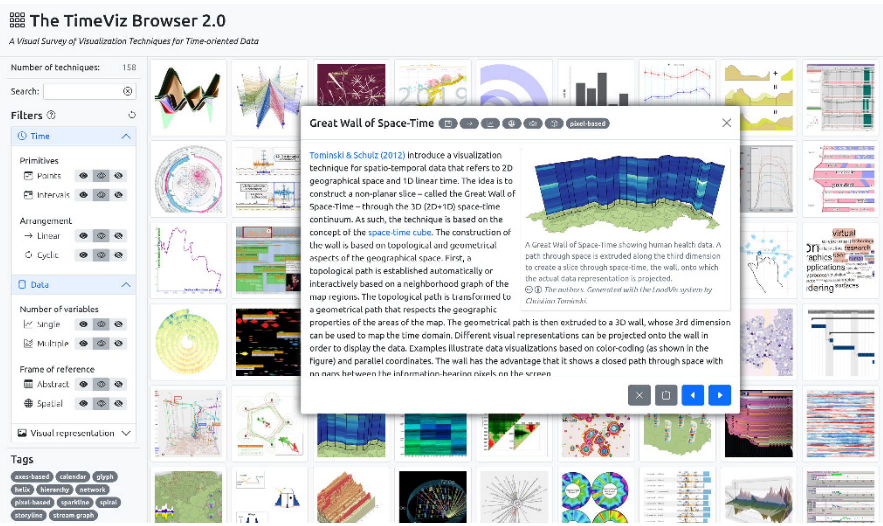

Fig. 7.1: The TimeViz Browser provides a visual overview of visualization techniques for time-oriented data and a filter interface for narrowing down the listed techniques according to six different criteria.

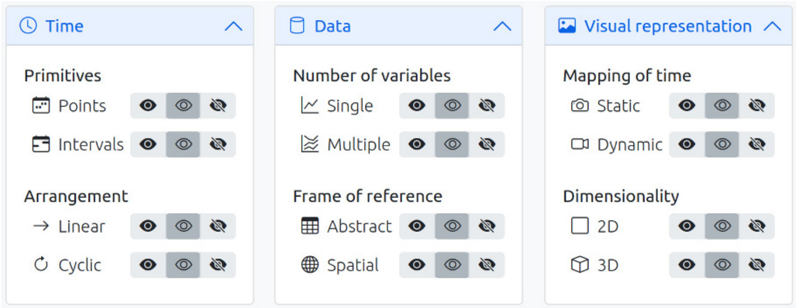

Fig. 7.2: Six filters grouped by data, time, and visual representation allow users to select visualization techniques that do or do not exhibit twelve different traits from six different categories.

Let us now take a closer look at how the TimeViz Browser works. Overall, it provides an overview of what is possible when visualizing time-oriented data. The diversity of visualization techniques is communicated visually by means of a collection of thumbnails, each showing a representative image of a visualization technique. Each technique can also be explored in greater detail. Selecting a technique opens up a detail view. This view offers a brief description of the technique, a larger figure, and a list of relevant publications. Small icons indicate the technique's place in the categorization schema (e.g., frame of reference: abstract vs. spatial or number of variables: single vs. multiple). Figure 7.1 shows a screenshot of the TimeViz Browser with the thumbnails in the background and the detail view on top of them. To the left of the figure, one can see the filter interface that allows users to narrow down the list of thumbnails.

This is where the TimeViz Browser utilizes the simplified categorization schema just introduced. There are six filters, one for each sub-criterion of the schema: primitives and arrangement (time), number of variables and frame of reference (data), and finally mapping of time and dimensionality (visual representation). As there are two categories per criterion, there are overall twelve filter controls in the interface (see Figure 7.2). Each filter control has three states *want*, *indifferent*, and *hide* based on which the list of thumbnails is filtered to allow users to express different interests. The want state of a filter signals the user's interest in techniques that belong to a certain category. So, by selecting *want*, the user asks the TimeViz Browser to show techniques that have a particular trait. Selecting indifferent literally means that the user is not concerned about a category. The hide state, on the other hand, is there to tell the TimeViz Browser to filter out techniques falling into a certain category. In short, for a visualization technique to be included as a thumbnail in the main view, it must satisfy all categories set to *want*, must not satisfy any category set to *hide*, and may or may not belong to categories set to *indifferent*.

Before we illustrate how the filters can be utilized to guide the search for suitable techniques in Section 7.4, we first provide a summarizing overview of the TimeViz Browser's corpus of available techniques in the next Section 7.3.

7.3 Overview of Visualization Techniques

The TimeVizBrowser covers overall 158 visualization techniques for time-oriented data. Table 7.1, which spans several pages, provides an overview of all techniques along with their categorization. Appendix A describes all listed techniques on a page-by-page basis, including a brief summary, an illustrative figure, and associated references. In a sense, Appendix A is like a static print version of the otherwise interactive TimeViz Browser.

Before we look at Table 7.1 in more detail, it is worth mentioning that it was not easy to decide on a good order for the techniques in the table. If we sorted by the name of a technique or by the year of its first publication, we would lose the semantic relationships of techniques, and similar techniques would be scattered across the table just because they have different names. Therefore, we looked for criteria in our categorization schema that would partition the corpus of techniques reasonably. A good first separation is possible with respect to the *frame of reference*. Accordingly, the table first lists abstract techniques and then techniques for data with a spatial frame of reference. At the next level of sorting, the techniques are ordered by the *number of variables* being visualized. Techniques for data with a single time-dependent variable will precede those for multiple time-dependent variables. At the subsequent levels, we order the techniques by their affiliation to the sub-categories *arrangement*, *primitives*, *mapping of time*, and *dimensionality*.

	time				**data**				**vis**				
	primitives		arrangement		frame of reference		number of variables		mapping of time		dimensionality		
	points	intervals	linear	cyclic	abstract	spatial	single	multiple	static	dynamic	2D	3D	page
Point Plot	■		■		■		■		■		■		232
Line Plot	■		■		■		■		■		■		233
Bar Graph, Spike Graph	■		■		■		■		■		■		234
Sparklines	■		■		■		■		■		■		235
TrendDisplay	■		■		■		■		■		■		236
Decision Chart	■		■		■		■		■		■		237
TimeTree	■		■		■		■		■		■		238
Arc Diagrams	■		■		■		■		■		■		239
SparkClouds	■		■		■		■		■		■		240
Growth Matrix	■		■		■		■		■		■		241
Multi-Resolution Visualization of Time Series	■		■		■		■		■		■		242
Pinus View	■		■		■		■		■		■		243
Ripple Graph	■		■		■		■		■		■		244

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Table 7.1: Overview and categorization of visualization techniques.

	time				data				vis				
	primitives		arrangement		frame of reference		number of variables		mapping of time		dimensionality		
	points	intervals	linear	cyclic	abstract	spatial	single	multiple	static	dynamic	2D	3D	page
Small MultiPiles	■		■		■		■		■		■		245
Time Maps	■		■		■		■		■		■		246
TimeDensityPlots	■		■		■		■		■		■		247
Interactive Parallel Bar Charts	■		■		■		■		■			■	248
TimeHistogram 3D	■		■		■		■		■			■	249
Intrusion Monitoring	■		■		■		■			■	■		250
Anemone	■		■		■		■			■	■		251
Dynamic Word Clouds	■		■		■		■			■	■		252
Gantt Chart	■	■	■		■		■		■		■		253
Set Streams	■	■	■		■		■		■		■		254
TimeSets	■	■	■		■		■		■		■		255
Perspective Wall	■	■	■		■		■		■			■	256
DateLens		■	■		■		■		■		■		257
Timeline		■	■		■		■		■		■		258
Paint Strips		■	■		■		■		■		■		259
PlanningLines		■	■		■		■		■		■		260
Time Annotation Glyph		■	■		■		■		■		■		261
SOPO Diagram		■	■		■		■		■		■		262
TimeNets		■	■		■		■		■		■		263
Storyline Visualization		■	■		■		■		■		■		264
Temporal Mosaic		■	■		■		■		■		■		265
Train Delay Uncertainty		■	■		■		■		■		■		266
Triangular Model		■	■		■		■		■		■		267
Cycle Plot	■		■	■	■		■		■		■		268
Tile Maps	■		■	■	■		■		■		■		269
Multi Scale Temporal Behavior	■		■	■	■		■		■		■		270
GROOVE	■		■	■	■		■		■		■		271
SolarPlot	■		■	■	■		■		■		■		272
Cluster and Calendar-Based Visualization	■		■	■	■		■		■		■	■	273
Enhanced Interactive Spiral	■			■	■		■		■		■		274
ClockMap	■			■	■		■		■		■		275
SpiraClock		■		■	■		■			■	■		276
Horizon Graph	■		■		■		■	■	■		■		277
VizTree	■		■		■		■	■	■		■		278
Time Curves	■		■		■		■	■	■		■		279
TimeSlice	■	■	■		■		■	■	■		■		280
Silhouette Graph	■		■	■	■		■	■	■		■		281
Recursive Pattern	■		■	■	■		■	■	■		■		282

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Table 7.1: Overview and categorization of visualization techniques.

	time				data				vis				
	primitives		arrangement		frame of reference		number of variables		mapping of time		dimensionality		
	points	intervals	linear	cyclic	abstract	spatial	single	multiple	static	dynamic	2D	3D	page
Lin-spiration	■		■	■	■		■	■	■		■		283
Spiral Graph	■			■	■		■	■	■		■		284
Spiral Display	■	■		■	■		■	■	■		■	■	285
Stacked Graphs	■		■		■			■	■		■		286
TimeSearcher 3, River Plot	■		■		■			■	■		■		287
Timeline Trees	■		■		■			■	■		■		288
Layer Area Graph	■		■		■			■	■		■		289
TimeSearcher	■		■		■			■	■		■		290
BinX	■		■		■			■	■		■		291
MultiComb	■		■		■			■	■		■		292
ThemeRiver	■		■		■			■	■		■		293
history flow	■		■		■			■	■		■		294
LifeLines2	■		■		■			■	■		■		295
Similan	■		■		■			■	■		■		296
VIE-VISU	■		■		■			■	■		■		297
TimeWheel	■		■		■			■	■		■		298
LiveRAC	■		■		■			■	■		■		299
CareCruiser	■		■		■			■	■		■		300
Braided Graph	■		■		■			■	■		■		301
CiteSpace II	■		■		■			■	■		■		302
ChronoLenses	■		■		■			■	■		■		303
Connected Scatterplot	■		■		■			■	■		■		304
DimpVis	■		■		■			■	■		■		305
FluxFlow	■		■		■			■	■		■		306
Line Density Plot	■		■		■			■	■		■		307
Matrix-Based Comparison	■		■		■			■	■		■		308
MultiStream	■		■		■			■	■		■		309
netflower	■		■		■			■	■		■		310
Optimized Stream Graphs	■		■		■			■	■		■		311
RankExplorer	■		■		■			■	■		■		312
Sankey Diagram, Alluvial Diagram	■		■		■			■	■		■		313
TACO	■		■		■			■	■		■		314
WireVis	■		■		■			■	■		■		315
MOSAN	■		■		■			■	■		■	■	316
3D ThemeRiver	■		■		■			■	■			■	317
Data Tube Technique	■		■		■			■	■			■	318
Kiviat Tube	■		■		■			■	■			■	319
Temporal Star	■		■		■			■	■			■	320

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Table 7.1: Overview and categorization of visualization techniques.

	time				data				vis				
	primitives		arrangement		frame of reference		number of variables		mapping of time		dimensionality		
	points	intervals	linear	cyclic	abstract	spatial	single	multiple	static	dynamic	2D	3D	page
Time-tunnel	■		■		■			■	■			■	321
Worm Plots	■		■		■			■	■			■	322
Software Evolution Analysis	■		■		■			■	■			■	323
3D TimeWheel	■		■		■			■	■			■	324
Vanishing-Point Plot	■		■		■			■	■			■	325
InfoBUG	■		■		■			■	■	■	■		326
Gravi++	■		■		■			■	■	■	■		327
CircleView	■		■		■			■	■	■	■		328
CloudLines	■		■		■			■	■	■	■		329
Animated Scatter Plot	■		■		■			■		■	■		330
Process Visualization	■		■		■			■		■	■		331
TimeRider	■		■		■			■		■	■		332
Flocking Boids	■		■		■			■		■		■	333
Time Line Browser	■	■	■		■			■	■		■		334
PatternFinder	■	■	■		■			■	■		■		335
FacetZoom	■	■	■		■			■	■		■		336
KNAVE II	■	■	■		■			■	■		■		337
Continuum	■	■	■		■			■	■		■		338
VisuExplore	■	■	■		■			■	■		■		339
Midgaard	■	■	■		■			■	■		■		340
LifeLines	■	■	■		■			■	■		■		341
EventRiver	■	■	■		■			■	■		■		342
Story Curves	■	■	■		■			■	■		■		343
TextFlow	■	■	■		■			■	■		■		344
Event-Flow Visualization	■	■	■		■			■	■		■		345
Co-Bridges		■	■		■			■	■		■		346
LiveGantt		■	■		■			■	■		■		347
PeopleGarden	■		■	■	■			■	■		■		348
PostHistory	■		■	■	■			■	■		■		349
Pixel-Oriented Network Visualization	■		■	■	■			■	■		■		350
Parallel Glyphs	■		■	■	■			■	■			■	351
Circos	■	■	■	■	■			■	■		■		352
Kaleidomaps	■			■	■			■	■		■		353
KAVAGait	■			■	■			■	■		■		354
SentiCompass	■			■	■			■	■		■		355
TreeRose	■			■	■			■	■		■		356
Intrusion Detection	■			■	■			■	■			■	357
KronoMiner	■	■		■	■			■	■		■		358

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Table 7.1: Overview and categorization of visualization techniques.

	time				**data**				**vis**				
	primitives		arrangement		frame of reference		number of variables		mapping of time		dimensionality		
	points	intervals	linear	cyclic	abstract	spatial	single	multiple	static	dynamic	2D	3D	page
Small Multiples	■		■	■	■	■	■	■	■		■	■	359
EventViewer	■	■	■	■	■	■	■	■	■		■		360
Ring Maps	■	■	■	■	■	■	■	■	■		■	■	361
ThermalPlot	■		■		■	■		■		■	■		362
Circular	■	■	■		■	■		■	■		■		363
ViDX	■	■	■	■	■	■		■	■	■	■	■	364
Value Flow Map	■		■			■	■		■		■		365
Flowstrates	■		■			■	■		■		■		366
Traffigram	■		■			■	■		■		■		367
Time-Varying Hierarchies on Maps	■		■			■	■		■			■	368
Great Wall of Space-Time	■		■			■	■		■			■	369
MoSculp	■		■			■	■		■			■	370
Flow Map	■	■	■			■	■		■		■		371
Visits	■	■	■			■	■		■		■		372
Time-Oriented Polygons on Maps	■		■	■		■	■		■		■		373
Growth Ring Maps	■		■	■		■	■		■		■		374
Trajectory Wall	■		■	■		■	■		■		■	■	375
Spatio-Temporal Event Visualization	■		■			■	■	■	■			■	376
Space-Time Cube	■	■	■			■	■	■	■			■	377
Space-Time Path	■	■	■			■	■	■	■			■	378
Icons on Maps	■	■	■	■		■	■	■	■		■	■	379
VIS-STAMP	■		■			■		■	■		■		380
Time-Ray Maps	■		■			■		■	■		■		381
Wakame	■		■			■		■	■			■	382
GeoTime	■		■			■		■	■	■		■	383
Multiple Temporal Axes Model	■	■	■			■		■	■		■		384
Data Vases	■	■	■			■		■	■		■	■	385
Pencil Icons	■	■	■			■		■	■			■	386
Temporal Focus+Context		■	■			■		■	■			■	387
Chro-Ring	■	■		■		■		■	■		■		388
Helix Icons	■	■		■		■		■	■			■	389
count	143	49	145	35	133	31	72	102	149	15	132	35	

Table 7.1: Overview and categorization of visualization techniques.

Table 7.1 provides an overview of the available techniques based on which we can already make some interesting observations about the state of the art. Next, we take a closer look at possible explanations for the observable balances and imbalances with regard to our categorization.

Time – primitives Points in time are the most commonly used time primitive in our corpus of techniques. This seems natural because data are often measured at a particular point in time. Intervals occur less often, for example, in planning scenarios, where it is important to know how long certain activities will take as in PlanningLines (↪ p. 260). Intervals also become relevant when data, while measured at a particular point in time, are valid in local scope, or when data need to be aggregated from individual points to intervals in order to deal with bigger and bigger datasets as in Midgaard (↪ p. 340).

Time – arrangement Most techniques support linear time; the approaches for cyclic time are significantly outnumbered. Reasons for this might be that users are usually interested in trends evolving from past, to present, to future, rather than in finding cycles in the data. The latter aspect, however, is important to fully understand the data, and therefore, expert data analysts need effective cyclic representations as offered, for example, by the spiral display (↪ p. 285) or Circos (↪ p. 352).

Data – number of variables The number of techniques for a single variable is roughly balanced with the number of techniques for multiple variables. While classic techniques often consider simpler univariate data, modern approaches take on the challenge of dealing with multiple variables. Our corpus also contains several techniques that cope with multiple variables simply by the repetition of a basic visualization design that only addresses a single variable. An example is the recursive pattern (↪ p. 282) technique.

Data – frame of reference In this book, we mainly focus on abstract data, which is also reflected in the list of techniques. Showing time-oriented data in a spatial frame of reference significantly increases the design efforts because more information has to be packed into the visual mapping. Particularly, the disciplines of cartography and geo-visualization, which are established, independent fields of research, have developed approaches to combining the visualization of temporal and spatial aspects of data (see Andrienko and Andrienko, 2006; Kraak and Ormeling, 2020).

Visual representation – mapping of time Apparently, the printed pages of a book are better suited for showing static techniques. In this sense, our corpus of techniques is biased in that it contains mostly static approaches. However, dynamic animation is equally important and often it is the first solution offered when time-oriented data have to be visualized. Animation can also be an option in combination with static methods to extend the capacity of a technique in terms of the data that can be handled. This strategy is for example followed by GeoTime (↪ p. 383).

Visual representation – dimensionality Two-dimensional visual representations are often preferred over three-dimensional ones, because they are more abstract and thus tend to be easier to understand. Especially techniques developed in the early days of computer graphics tend to stick with two dimensions simply due to the limited computing power available then. However, modern technologies have made it easier both for visualization designers to implement three-dimensional visualization and for visualization users to navigate and explore virtual 3D visualization spaces. This is particularly useful when data with spatial references have to be visualized (e.g., space-time cube (↪ p. 377) or space-time path (↪ p. 378) techniques).

There is another significant fact that can be derived from the corpus of existing visualization techniques: Most approaches address the model of an *ordered* time domain, while only a few of them explicitly consider the visualization of *branching* alternative strings of time, and none of them is capable of visualizing data that are based on the model of *multiple perspectives*. Although there is one technique, called story curves (↪ p. 343), which at least include two perspectives on time in the visualization. Still, branching time and time with multiple perspectives deserve more research attention in the future.

It is also visible that the majority of techniques are specific to a particular *what* and as a consequence represent tailored solutions in terms of *how* the data are visualized. An advantage of such specific solutions is that they are fine-tuned to be successful in supporting a specific category of time-oriented data. The downside, however, is that these solutions are hard to adapt and reuse for other visualization problems, even when a new problem is similar to the original one and differs only in one aspect of our categorization schema.

In summary, there are very many different techniques for visualizing time and time-oriented data. This can be both a blessing and a burden. While we can choose from a variety of options, the decision may not be easy.

7.4 Guided Search for Visualization Techniques

Next, we look at concrete example scenarios that illustrate how one can reduce the 158 visualization techniques included in our corpus to a much smaller set of promising candidates. The TimeViz Browser can guide the search for appropriate techniques based on the simplified categorization schema.

As already mentioned, the schema includes selected aspects of the time dimension and the data (what) as well as the visual representation (how). Aspects of analysis tasks (why) are not included. Therefore, in the second part of this section, we outline a theoretical framework for a multi-faceted selection process that covers all relevant aspects. We also indicate the challenges of applying this framework in practice.

7.4.1 Example Scenarios

Let us start with two concrete examples illustrating the process of selecting appropriate visualization techniques with respect to time and data (what) and also with respect to preferred visual representations (how).

Visual Exploration of Work Time Patterns of Employees

For our first example, we take the role of a manager of a manufacturing facility. As a manager, we would like to visually explore time patterns related to the work times of employees in order to better plan work schedules. The data originate from a time tracking system, which provides employee information along with time interval data for the start and end times of work sessions. The time primitives we need to analyze are intervals and as we do have a 24/7 production schedule with regular work schedules, we would like to mainly focus on cyclic time. Our data include multiple variables and have no spatial context.

With this scenario in mind, we now use the TimeViz Browser to find suitable visualization techniques. We start with the TimeViz Browser showing all 158 techniques. The search process is based on adjusting the filters according to the time and the data at hand.

What First, we filter for visualization techniques that support interval-based data. This already reduces the number of techniques by about 60%, but there are still very many. Second, we focus on techniques for cyclic time, which reduces the result set substantially. Third, as we need to show multiple aspects of employee data, we filter for techniques supporting multiple variables. However, there is only one techniques that does not fulfill this criterion, so we do not get much of a reduction with this filtering step. Fourth, as we do not have spatial data, we hide the techniques for data with a spatial frame of reference. As a result, the TimeViz Browser eventually lists three techniques suitable for our data, including Circos (↪ p. 352), KronoMiner (↪ p. 358), and Spiral Display (↪ p. 285). We can now further assess these techniques with respect to their visual representation (how), which is easily doable using further filters.

How As we want to use the visualization of our employees' work times as an argument in a managerial report, we must use a static mapping of the dimension of time. Moreover, printed visualizations in a report are preferably kept in 2D. We set the corresponding filters in the TimeViz Browser to match these requirements. However, no further reduction of the suitable techniques is possible.

Still, our interactive search was successful overall. We could reduce the problem of choosing from 158 possible techniques to the much easier task of making a choice among three techniques, for which we know they match our needs in terms of time, data, and visual representation.

Dynamic Visualization of Financial Time Series in an Immersive Display

In the second example, we take the role of a visualization designer. As a visualization designer, we have been commissioned to create an immersive experience of stock market data to be on display for an event of a bank. Our users will be interested customers and stakeholders, who will be provided with virtual reality (VR) headsets at an information booth in the lobby of the bank. The data to be visualized consist of daily stock prices of the national stock exchange over the last three years. Our client wants the dynamics of stock price changes to be made visible and for the bank's strategic actions to visually match the patterns in the data.

The time primitives to be displayed are points, as we get stock price readings for each trading day. The time series are given on a linear time scale and we have multiple stocks to represent. Furthermore, the data are not spatially anchored. Again, we adjust the filters in the TimeViz Browser accordingly.

What First, we select points as the time primitives and linear time as the time arrangement. However, since most techniques meet both of these criteria, the reduction is rather small at about 10%. With still too many techniques being listed, we next hide visualization techniques that can show only a single variable and those that deal with spatial data. Unfortunately, still several dozens of techniques are in the pool of potential candidates. We need to distill them further by filtering with respect to the visual representation.

How The dynamics in time-oriented data can be represented nicely with the use of a dynamic mapping. We set the filter in the TimeViz Browser accordingly. Now we get a substantial reduction in the displayed candidates to less than ten. Moreover, our visualization is to be used in an immersive VR setting. Therefore, we filter for techniques that use a 3D visual representation. Eventually, this results in only a single suitable technique: Flocking Boids (↪ p. 333).

Again, with a few clicks in the TimeViz Browser's filter interface, we were able to find suitable visualization techniques, exactly one in this case, for our problem at hand. These two successful examples, however, should not hide the fact that we may be less successful in other scenarios. Therefore, we need additional leverage points to further support the guided search. For this purpose, we next outline a multi-faceted selection process.

7.4.2 Towards a Multi-Faceted Selection Process

The selection of appropriate visualization techniques for a particular application purpose is a multi-faceted and iterative decision-making process that can be delicate and overwhelming. It is necessary to take into account a number of aspects concerning the data, the users, their tasks, the used devices, as well as the usage contexts at hand. To cope with this complexity, it makes sense to follow a structured, multi-faceted selection process that narrows down the number of visualization options step by step. Figure 7.3 provides an overview of the aspects to be considered. It extends the what-why-how structure introduced at the beginning of this book along the Five W's and How tool (see Hart, 1996):

1. What: time and data
2. Why: tasks
3. Who: users
4. Where: devices
5. When: contexts
6. How: visual representation

What is presented? – Time & data As can be seen in Table 7.1, literally hundreds of different visualization techniques exist. In a first step, this set can be narrowed down by discarding techniques unable to visualize the data and time characteristics present in the data. A prerequisite for this is the identification of data and time characteristics present in the data to be visualized. To support this step semi-automatically, we can use the TimeViz Browser (`https://browser.timeviz.net`) with its interactive filter interface to narrow down a candidate set of visualization techniques. Usually, such an initial filtering based on the *what* aspect leads to a reduction to dozens of potentially suitable techniques.

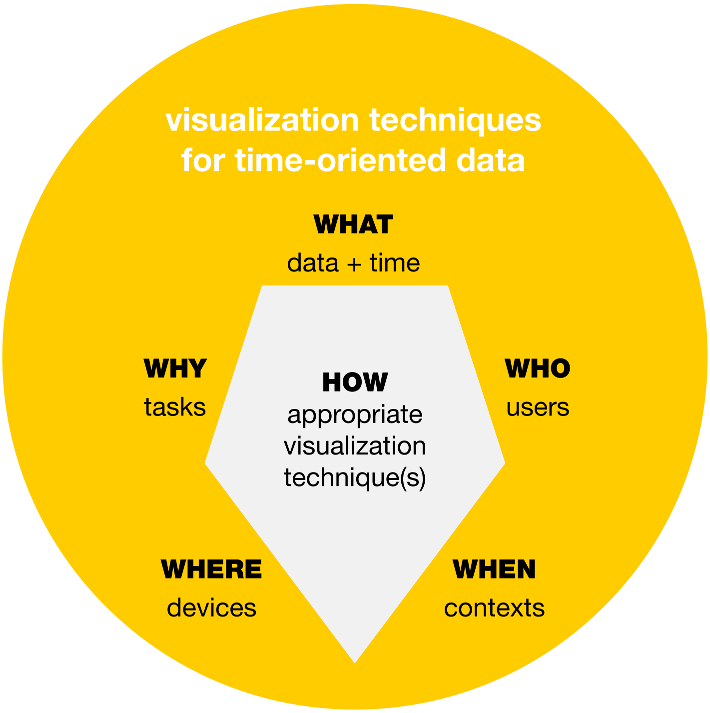

Fig. 7.3: Multi-faceted selection of appropriate visualization techniques.

Why is it presented? – User tasks To narrow down the number of suitable solutions further, we must consider why a user needs or is provided with a visualization. A prerequisite for this is the process of *task abstraction*, that is, the identification of user tasks to be supported by the visualization. A useful framework to systematically consider user tasks particularly in the context of time-oriented data was discussed in Section 4.1.2. Depending on the set of tasks relevant for the problem under consideration, further visualization approaches can be discarded that do not provide the necessary identification, lookup, or comparison support. It might also be the case that a combination of different visualization techniques in a multiple-views approach is necessary to address all the data and task requirements. A difficulty though is to categorize existing techniques with respect to the tasks they support. More research is needed to come up with validated categorizations, which could then also be picked up by the TimeVizBrowser to further support users in their search.

Who is the presentation for? – Users In order to be able to cater to the needs of a specific user group, it is necessary to take into account who the users will be. This includes gathering as much information as possible to better understand the target group. For example, aspects about the application domain, age group, educational background, visualization literacy, domain knowledge, or already known visualization concepts can provide essential rationales for further prioritization of techniques. Again it is also necessary to categorize existing techniques according to the *who* aspect, which also represents a formidable task for future research.

Where is it presented? – Target devices In addition to the data and human-centered aspects of the previous questions, technical aspects of display and interaction devices to be targeted are crucial. For example, visualization techniques that are appropriate for certain *what* and *why* aspects might after all not be feasible for being used on small smartphone screens or with touch interaction. In the context of visualization, the most important aspects are the display capabilities for visual output (e.g., screen size, aspect ratio, resolution, and available colors) as well as the input modalities offered (e.g., pointing device, touch interaction, and physical interaction).

When is it presented? – Contexts Questions regarding the concrete usage environments, i.e., the specific contexts in which a visualization is going to be used, tie together all the other aspects considered so far. Consider, for example, data variables of a car (*what*, e.g., rpm, velocity, and fuel level) to be used by engineers (*who*) for monitoring the variables' changes over time (*why*) on a tablet device (*where*). Depending on whether the intended usage context is next to a test stand inside a factory building or inside a car while driving it at the same time, suitable visualization techniques will be quite different from each other for either case. Practically, the *where* and *when* aspects are often closely interrelated. For example, if a visualization for informing bike riders on the go should be provided, small screen mobile devices appear to be most suitable. What's more, if we have a visualization on a small screen mobile device, it lends itself to be used in contexts where users are moving.

How is it presented? – Visual representation Applying the considerations that result from the answers to the five W's leads to a candidate set of appropriate visualization techniques. Each of these techniques provides an answer to the final *how* question: how is it represented? As we've learned in Chapter 4 and from the TimeVizBrowser, the how aspect for the visualization of time-oriented data is mainly categorized by the differentiation of static and dynamic as well as 2D and 3D representations. These characteristics can also be used to further narrow down the set of appropriate visualization techniques (e.g., if a stereoscopic, head-mounted display is the target device, a 3D representation might be more suitable).

The multi-faceted selection process outlined above is informed by user research as well as data and task abstraction steps. Parts of the process can be semi-automated, such as selecting appropriate techniques using the TimeViz Browser. Other stages have to be individually curated by the visualization designers or users themselves who are responsible to decide which of the appropriate techniques match their needs.

It is important to understand that the selection (as much as the design) of appropriate visualization techniques is usually not a linear, clearly defined sequence of steps. The involved decisions are often not independent and may influence each other. All the mentioned W-questions contribute to a well-informed decision-making process of a visualization designer or user. Moreover, in different situations, different subsets of facets might be given as constraints while in other cases these are up for the user or designer to decide. As an example, the target devices to be used might be fixed (e.g., as service technicians are already equipped with small screen handheld devices of some kind) whereas in other cases the choice of target devices might be up to the designer who makes this selection based on the other given facets (e.g., based on a specific user group that needs to be supported in a specific context such as health workers on their ward). Answers to one of the questions might also be in conflict with answers to other questions and lead to reconsiderations, iterative refinements, or the need to revisit facets. In other cases, it might not be possible or necessary to consider all facets for the selection process, for example, if the set of suitable techniques is already down to a single possible one.

So far, we have provided an overview and checklist of aspects to possibly consider when selecting visualization techniques for time-oriented data. Although there is no strict order to be followed when considering the W-questions, starting with the *what*, the characteristics of data and time, as well as the *why*, the tasks to be supported, makes sense in many cases. For further narrowing down this set of available solutions, considering the aspects of users, devices, contexts, as well as the visual representations allows for distilling down to visualization techniques suitable for a given domain problem. Figure 7.4 provides an overview of this process for guiding the selection of suitable visualization techniques.

What's more, we primarily focused on the *what*, *why*, and *how* aspects so far, since these are to a large extent influenced and determined by the special characteristics of time, which this book is about. However, it is equally important to take into account the aspects of the users (who), target devices (where), and the usage contexts (when). Given our time-oriented focus, we do not go into the details of these more general facets, but refer the interested reader to the general literature on visualization design (see Munzner, 2014; Kirk, 2019).

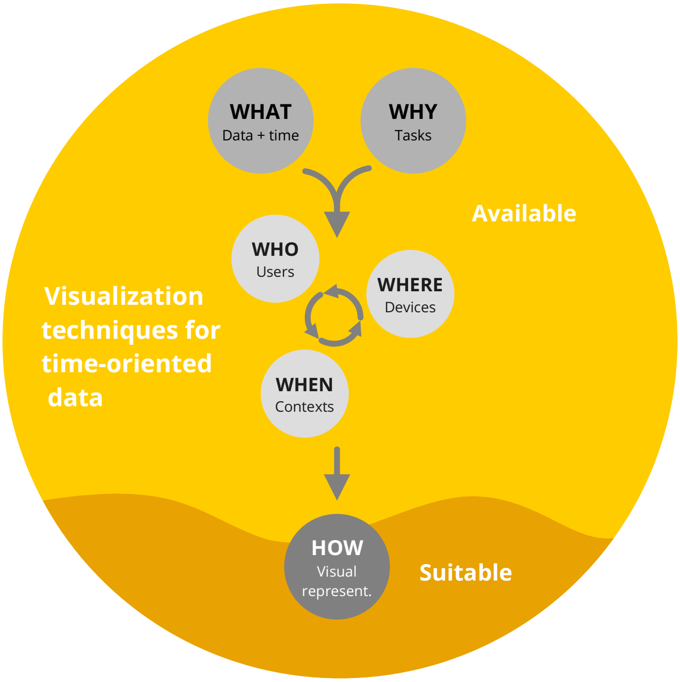

Fig. 7.4: Process of guiding the selection of suitable visualization techniques.

7.5 Summary

This chapter was concerned with the practical question of selecting visualization techniques for time-oriented data for a given data analysis problem. We introduced a simplified categorization schema for existing techniques and employed this schema in the TimeViz Browser to guide the selection of suitable visualization techniques. To this end, the TimeViz Browser maps the categorization schema to an interactive filter interface allowing users to narrow down their search for visualization techniques.

The TimeViz Browser is based not only on the simplified categorization schema, but also on a large corpus of 158 categorized visualization techniques. While the individual techniques of this corpus are described in Appendix A, this chapter looked at the corpus as a whole and derived some interesting observations with respect to the distribution of techniques in the different categories. The detailed descriptions in the appendix will reveal that some general concepts reoccur in several instantiations, as for instance the general application of line plots as the most basic visualization of time-dependent data, the utilization of the third display dimension to encode time, or the mapping of time to spiral shapes in order to visualize cyclic aspects.

While the TimeVizBrowser is a great tool to support the selection of visualization techniques, it does not cover all aspects that might be relevant for such a selection.

Therefore, we also outlined a conceptual framework for a multi-faceted selection process that addresses the relevant aspects more broadly. We indicated the benefits of such an elaborate selection process and also mentioned the challenges to be tackled in future research to make the process practically applicable.

In the next and final chapter of this book, based on the insight gained so far about existing visualization techniques, we discuss remaining practical concerns, outline the tight integration of visualization, interaction, and computational methods under the umbrella of visual analytics, and present opportunities for future research.

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