Graphical representation of the comprehensive patient flow through the Hospital

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Abstract

Representing the patient flow through the hospital is quite a difficult task, considering the amount of data to be taken into account. In this article, some usual visual representations are first shown, then new charts are proposed. Several real examples are given. Those charts have been implemented in a web-based query interface, using PHP5 and generating SVG outputs on the fly, without any a priori knowledge.

These charts allow for representing a large amount of data on the same graph: the occupancy of each medical department, their linking and transfers, allowing to display the whole care sequence. SVG, an XML-based free vector graphics format, allows rich end-user interaction. Practical applications: length of stay reducing, cost reducing, cost breakdown, further statistical study, administrative authorizations…

Keywords: *Medical Informatics, Computer Graphics, Patient Flow Analysis, Charts, SVG.*

Introduction

Rationale

In the current context of activity rating, hospitals are trying to improve the quality of care and the patients' satisfaction, while decreasing the length of hospitalization and reducing costs. A part of the problem consists in optimizing and controlling the flow of patients between medical departments. Those flows are linked with real medical justifications, but also with consequences of organization defaults, or irrational habits. In this purpose, representing and analyzing the patient flow is a real necessity.

Complexity of the patient flow

Characterizing the patient flow through the hospital is quite complex, due to the diversity of the stays, as shown in example (Figure 1 & Table 1). This diversity could be summed up as follows:

- External components:
  - Entry mode (from home, birth, transfer)
  - Exit mode (to home, death, transfer)
  - Length of the complete stay

- Internal components:
  - Succession of hospitalization settings (emergency, surgery, intensive care…)
  - Internal transfer from a medical department to another, date of this transfer
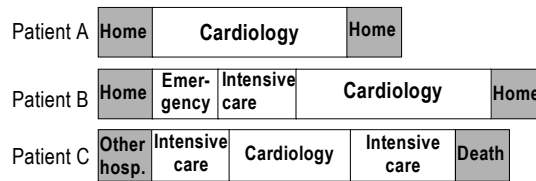 - Length of the consecutive parts of the stay

Figure 1. As shown by those examples, the patient flow through the hospital can vary by many aspects.

Patient	Entry mode&date		Exit mode&date		Department
A	Home	03/01	Home	03/05	Cardiology
B	Home	04/01	Transfer	04/01	Emergency
B	Transfer	04/01	Transfer	04/04	Intensive care
B	Transfer	04/04	Home	04/11	Cardiology
C	Other hosp	06/01	Transfer	06/01	Intensive care
C	Transfer	06/01	Transfer	06/05	Cardiology
C	Transfer	06/05	Death	06/09	Intensive care

Table 1. Computerized statement of the data above.

Usual visual representations

Traditional charts are mostly used to represent external components. Some examples of those charts are shown below.

Bubbles charts (Figure 2) are often used to represent the number of patients in respect of the combination between entry and exit modes.
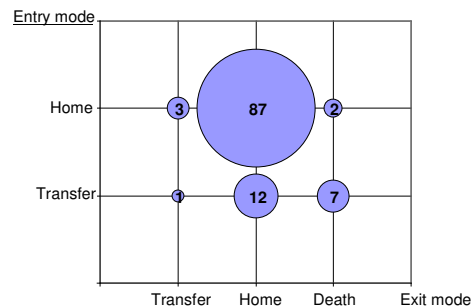

Figure 2. Bubbles charts are often used to represent the entry and exit modes of the patients.

Qualitative variables, such as the entry point into the hospital, can be represented using pie charts (Figure 3). But in order to represent the hierarchical organization of the hospital with another quantitative variable, Squarified Treemaps seem to do a better job [1-3].
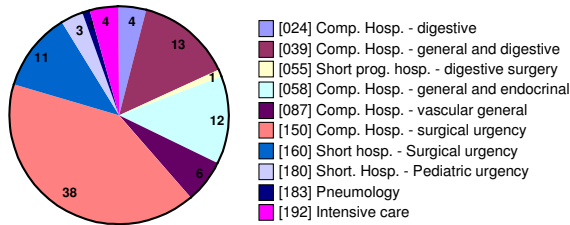

[024] Comp. Hosp. - digestive
[039] Comp. Hosp. - general and digestive
[055] Short prog. hosp. - digestive surgery
[058] Comp. Hosp. - general and endocrinal
[087] Comp. Hosp. - vascular general
[150] Comp. Hosp. - surgical urgency
[160] Short hosp. - Surgical urgency
[180] Short. Hosp. - Pediatric urgency
[183] Pneumology
[192] Intensive care

Figure 3. Pie charts are widely used. Here, the entry points of patients suffering from surgical digestive diseases are represented.

The total length of stay can be represented by the cumulative proportion of stays (Figure 4), which looks like a survey curve. This chart represents, for each x length, the proportion of patients staying at least x days in the hospital. Several curves can be superposed.
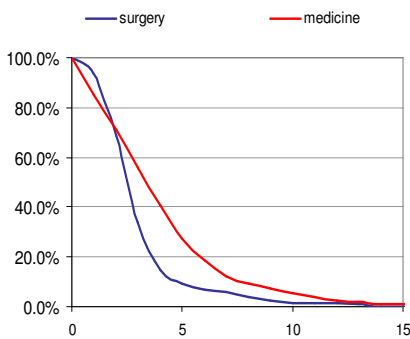

Figure 4. Cumulative proportion curves allow to represent the duration of stay.

All of the former charts are useful when the author already knows what points are to be shown, and wants to explain them synthetically. But they do not allow him to explore those complex situations without any *a priori* knowledge. Patient flow analysis (PFA) usually combines all those methods in a handmade study at a given time [4].

Finally, many kinds of charts aim to represent networks or relationships [5, 6]. They seem to be seldom used in that field. Markov models and related graphics are often used in medicine [7]. Their aim is to conceptualize probabilistic transition networks: we don't want to compute transition probabilities, but to show when and where those transitions really occur. The basic assertion of Markov models is that a transition depends on the previous state, and is independent of the penultimate state, which is naturally not true in this case. On the contrary, we need to display the complete flow of the patients, from the entry to the exit.

Material & Methods

Approach

New charts have to be created in order to represent the internal components of the patient flow through the hospital. Those charts have been implemented in a web-based interactive software.

A large database contains the whole activity of the hospital. To extract the relevant information from this database, the user can define the selection criterions ("where" SQL clause). A query is then submitted to the database. The answer is analyzed, and a graphical output is generated on the fly. The user can explore it interactively on screen by simply using the mouse (Figure 5). This interface can be used from any networked computer in the hospital.
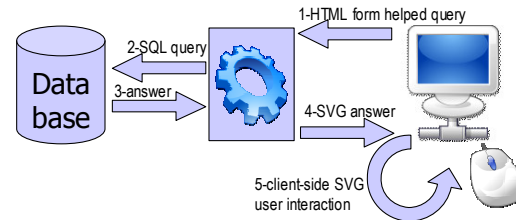

Figure 5. A web-based interface allows to explore the database by generating a SVG graphical output on the fly.

Implementation

PHP5 (Php: Hypertext Preprocessor) [8] was chosen to implement those charts. PHP makes it possible to generate JPEG files by using the GD2 library [9], and to write text files, thus generating SVG graphics.

SVG (Scalable Vector Graphics) is an XML-based format [10-12] and was chosen as the graphical output format. The graph's description is written in formatted text according to the XML standard. The Web browser interprets the XML code and displays a vectorial graph.

- Advantages:
  - The end-user can zoom in and out without any loss of quality.
  - The programmer can allow end-user interaction, implementing mouse event listeners.
  - In a static approach, the imperfections of SVG graphs could be manually improved using a

vector graphics editor such as InkScape [13, 14], or using a text editor, assuming SVG standards are known.

- Being a vectorial format, SVG allows high quality printing.
- Disadvantage: some Web browsers must be equipped with a free plugin such as Adobe SVG Viewer for Internet Explorer [15] (free). Some other browsers natively support SVG, for example Mozilla Firefox [16], but the implementation of ECMAScript seems to be incomplete.

Results

All the following charts have been generated using real unbeautified hospital data. The charts have been generated on the fly by our online application and have not been modified.

Transfer matrix

It is quite usual to quantify the internal transfers between medical departments: this leads to produce a transfer matrix. Medical departments are represented on both axis of the chart. Each square represents the number of patients transferred between the two considered departments. Numbers are replaced with colors according to a black-red-yellow-white scale (Figure 6) but "mouse-over" effects allow to read them. The first example shows the internal transfers of patients suffering from appendicitis (Figure 7). This representation becomes more interesting when the chart includes more patients. The second example shows all the digestive surgery stays (Figure 8). It highlights how the interpretation is fast and intuitive:

- Hot-spots identify the major flows.
- Horizontal lines allow to identify medical departments that discharge a lot of patients.
- Vertical lines allow to identify medical departments that receive a lot of patients.

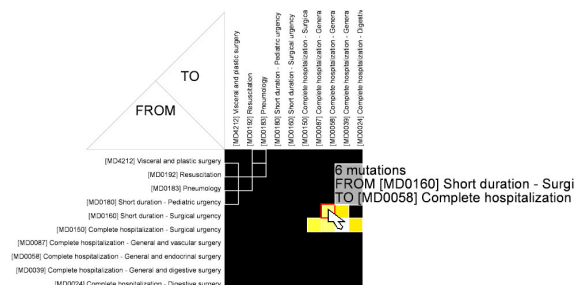**Figure 6.** Black-red-yellow-white color scale

Figure 7. Colored transfer matrix and "mouse-over" effect (appendicitis)

However, the interpretation of such a matrix leads to incomplete results:

- the length of the complete stay, and the length of its parts are still missing
- the stays that are not shared by several medical departments are not represented
- the internal transfers are quite difficult to interpret if many patients go through more than 3 medical departments.
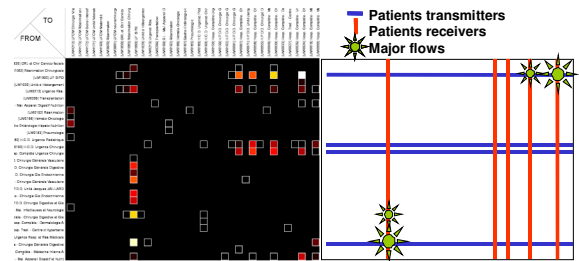
Figure 8. Colored transfer matrix and interpretation (whole digestive surgery)

Representing the comprehensive flow

Principle

Following that observation, we developed a new modality of representation, shown in Figure 9. This chart allows to represent at the same time the occupancy of the medical departments (MDs) (besides the partial length of stay) and the internal transfers between the MDs (including: the origin, the destination, the date, the number of involved patients). The same scale is used in both cases to represent the thickness of the elements.

An iterative algorithm automatically places the MDs on the vertical axis so that the representation of the transfers looks as simple as possible. The horizontal axis represents the time, growing from left to right. The patients are represented as if they had all arrived at the hospital on the same day. This first day stands on the left of the chart. The green rectangles represent the patients who are still in the MD day after day.

When one or several patients are transferred from a MD to another, a curve is drawn. The width of the curve is proportional to the number of involved patients. In order to differentiate those curves, ascending transfers are represented by blue and right-hand curves, when descending transfers are represented by pink and left-hand curves. Small arrows were added.

First example

The first example deals with the patients suffering from appendicitis (Figure 9). We immediately identify two medical departments (MDs) as major
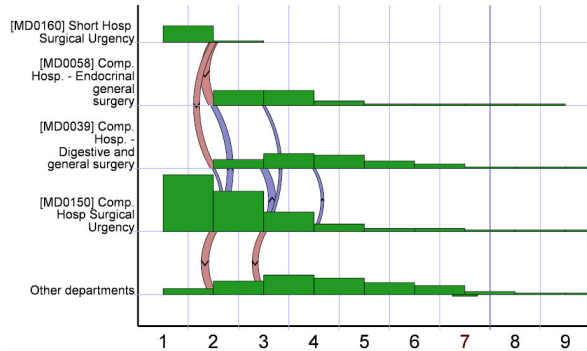
Figure 9. Patients suffering from appendicitis enter into the hospital via MDs 160 and 150. Thereafter, some of them are transferred to MDs 58 and 39. The abscise axis represents the elapsed time in days.
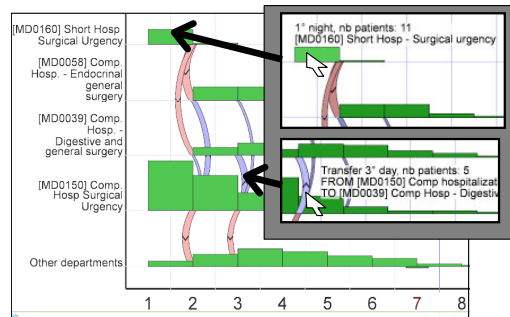

Figure 11. "Mouse over" effects allow for getting information about the occupancy of MDs and about transfers.
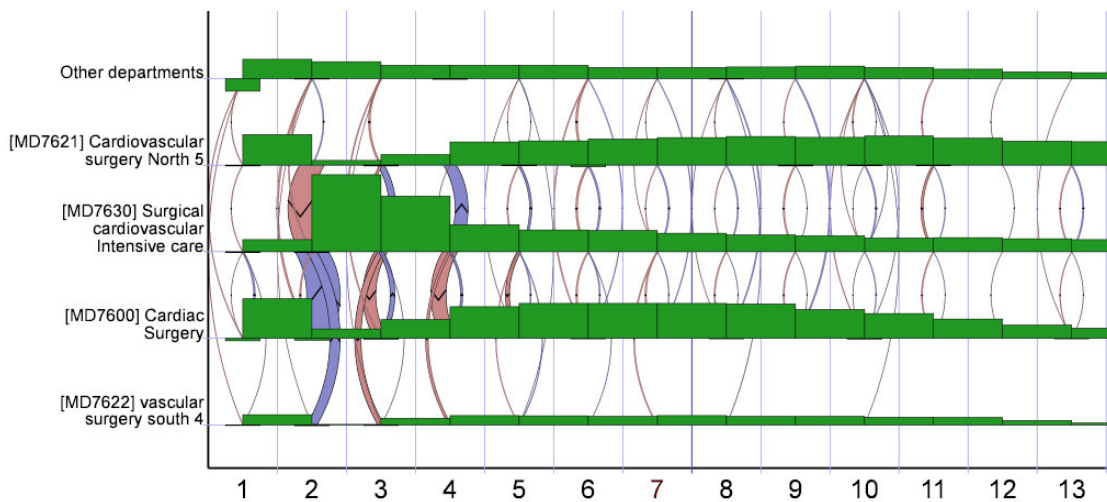

Figure 10. Patients going through MD7630. Most of these patients come from MDs 7621, 7600 and 7622 the day after admittance, stay there a few days and return to those MDs for a quite long duration.

entry points: MD160 and MD150. But their profile totally differ. Entering via MD160, the patients are automatically transferred to MD058 and MD039 the day after their admission. They will stay 2 or 3 days there and return home. Entering via MD150, most patients will stay there a few days and will directly go back to home, although some patients will be transferred to MD058 MD039 and other departments. Opposite to MD160, MD150 manages itself the patients' return to home. Globally, the stays look quite short, less than a week long.

At any time, "mouse-over" effect allows the user to get textual information about the occupancy of the MD and about the transfers (Figure 11). The browsed shape moves to the foreground, becomes highlighted, and visual textual information is added.

Second example

In this second example (Figure 10, which had to be right truncated), patients going through MD7630 are

selected. MD7630 is a surgical cardiovascular intensive care department. The interpretation is simple and immediate, although the data are quite complex:

- The stays look globally quite long.
- MD7630 principally works with 3 others MDs. Other departments only represent a few stays.
- Those stays are very stereotyped: patients enter via MD7600, MD7621 or MD7622, are probably operated on the day after their entry, and they are immediately transferred into MD7630. They stay there many days then go back to their initial MD. The initial MD will manage the return to home. Some other backward and forward transfers are performed during the patients stays.

Discussion

It is necessary to create new graphical representations to synthetically represent the patient flow through the

hospital and transfers between medical departments. It could improve the way patients are taken care of, shorten the patients stays, and contain the costs. In this field, the second chart and its implementation have several advantages:

• Simple use, immediate results.
• The chart allows to represent a lot of various information in the same figure.
• SVG outputs allow interactive exploration, zoom in and out facility, additional information display, and high quality printing.

Moreover, this second kind of chart has already been used successfully in several domains:

• In the field of Transient Ischemic Attack: understanding the care habits and the MDs relationships, reducing the length of stay.
• In the field of financial distribution between MDs: understanding the reason why some MDs are extremely sensible to the choice of the repartition algorithm being used.
• In the field of administrative authorizations: justifying the need for additional intensive care beds.

However, some weak points are to be taken into account:

• This chart is quite unusual, and requires a little training. Although they seem quite natural, outputs should be explained to the physicians.
• As expected, no other existing software already proposes this kind of graphical output.
• This chart cannot jointly represent a second variable, in order to emphasize an association: neither a quantitative variable (such as average age), nor a qualitative variable (such as sex).
• In order to appreciate the length of stay, this chart should be complemented by survey curves or distribution charts (histograms, boxplots).

At the moment, some information is still missing:

• The location and the date of the main surgical act if necessary
• The origin and the final destination of the patients (home, birth, death, transfer)

Conclusion

The patient flow through the hospital is quite a complex set of elements to represent. The charts that are proposed here could help to understand how the patients are taken care of. This first step is very important in order to improve the global quality of care, especially for specific patients stays (entering via the emergency department, including intensive care, post-operative monitoring…).

Generally speaking, statistical tools allow to prove a noticed point. But before that, the issue is to be able to notice the point of interest, which issue could be difficult considering the large amount of datasets. In this purpose, synthetical visual tools as those ones are really needed.

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