Order on the Underground

Subway maps provide a clear overview of complex transportation networks. So far this has been done manually, but two IT experts recently reassigned this fiddly task to the computer.

Text: Stefanie Schramm Every big-city dweller knows it (often off by heart), every commuter faces it on a daily basis, every tourist uses it to plan their city sightseeing itinerary. The subway map is an everyday tool for life in the city. These maps have a design that is intensely fascinating. "People love maps. They display a huge number of opportunities: Where might I go, what connections work the best?" says psychologist Maxwell Roberts of Britain's University of Essex.

Maps of famous subway networks are more than just colored lines on paper, something that is particularly true of the London "tube" map. "The London Underground diagram paints a mental picture of the city. It has become a cultural icon; it is London," writes Mark Ovenden in his book "Transit Maps of the World." Many artists and designers have drawn inspiration from the natural aesthetic of subway maps. And subway enthusiasts have invented imaginary maps, discovered animals in the maze of their city subway lines, and rearranged the letters of station names to create new words. At first glance, creating a subway map is simplicity itself – all you need is the lines, the stations, the intersections, and you have it. But achieving a sufficient degree of simplicity that allows the traveler to identify the optimal route to their destination with just one look requires a great deal of highly complex work.

Simplifying Reality

If one were to simply draw the different branch lines and subway stops on a standard map of the city, as indeed was the case in the early years of the subway, transit users would rapidly lose any overview of today's complex networks. City centers would become a contorted mess of stations and interchange options, while the suburbs would have only stationless expanses for large stretches of the lines.

The art of designing a clear subway map requires a new approach to reality, one that entails simplification, magnification and compression. The question is how, and also how much? At what point does the map first become comprehensible thanks to the distortion of reality? And how much of the real structure should be retained to ensure that the plan remains decipherable?

This is more than just a tricky theoretical problem. A good subway map can also make an indirect contribution to reducing traffic congestion in the city and protecting the climate. "If people find an urban transport map easy to understand, they will also use public forms of transport more often," reckons psychologist Roberts. Until recently, such plans have been designed by hand, involving considerable racking of brains, erasing of errors and redrafting. True, computers have now been brought into play, but only in the capacity of a drawing tool. Independently creating a subway map with a computer was not an option. But four years ago, German IT expert Martin Nöllenburg and his colleague Alexander Wolff at the University of Karlsruhe began to teach their computer to undertake just this kind of Herculean task. A prototype of the program was ready after just a few months.

Drafting a subway map is a complex form of calculation for the mathematician: If the number of stations doubles, the computer doesn't just need twice or even four times as long to calculate a solution. It requires a much more extreme multiple.

The famous problem of the commercial traveler illustrates this: A sales representative needs to travel to a large number of towns to introduce his products in person. Which route is the shortest? The principle is a simple one, involving a straightforward comparison of all possible routes. In the case of four towns, whereby one must be the starting point and another the final destination, there are three variants to choose from (actually six, but the order in which the towns are covered makes no difference). With eight destinations, however, there are suddenly 2,520 options, and with 16 stations 653,837,184,000! This is enough to make even the fastest computer capitulate.

Helpful Set of Rules for the Computer

For this reason, the key is to help the computer by setting the parameters for the task in such a way that it does not try to find the best solution, but one that is good enough. As for what solution is "good enough," this has to be written into the program. Where subway maps are concerned, Nöllenburg and Wolff arrived at the following set of rules:

1. The lines may only be drawn horizontally, vertically or diagonally at an angle of 45 degrees. This was the trick with which the Englishman Henry Beck revolutionized plans in the 1930s (see box).

2. The topological structure of the network must be preserved: Every station on the network must be linked with other stations in the same order as in reality. >

Photo: Mathias Hofstetter

More than just an object of everyday use: The map of the London Underground is celebrated as an icon of cult status. It is essentially based on a map drawn up by the Englishman Henry Beck in 1933.

London's Tube Network as a Geographical Representation of Reality

While the different underground lines in the suburbs lose the reassuring regularity of stations, the city center is a jumble of chaos.

The London Underground Network as Drawn Up by Computer

If a subway map is to be understood, reality needs to be simplified by means of magnification and compression.

Maps: Nöllenburg, Wolff

Above:
The original London Underground map from 1920 is a close approximation of geographical reality, and accordingly provides no clear overview.

Middle:
In 1933, Henry Beck simplified the map by straightening the lines, setting diagonal lines at 45 degrees, and standardizing the distance between neighboring stations.

Below:
Psychologist Maxwell Roberts is convinced that arc-shaped line layouts make the London tube map easier to understand.

3. The gaps between stations along a line must have a minimum length.

4. Each line must be set a minimum distance away from other lines.

In addition to these rules, a couple of less rigorous criteria also come into play, for example each subway line having the fewest number of kinks possible. As Nöllenburg explains, this reduces a complex problem to a manageable one: "The computer doesn't always have to take into account all the rules, only the most important ones."

The approach taken by the IT experts to the subway problem was the right one. "This is the kind of practically relevant task that is rarely found in theoretical computing. And you can test the solution out by the way it looks," observes Nöllenburg, who often has trouble when faced with the simple task of actually using a subway map. Ways of improving what he sees often whirr away in the back of his mind. "I commute every day between Heidelberg and Karlsruhe. There are many unnecessary kinks in the line on the local S-Bahn map. It does annoy me a bit."

Moscow's Circular Ring Line

He particularly admires the London tube map – which is hardly surprising, as even today it essentially adheres to Beck's rules. But Nöllenburg also finds the Moscow map aesthetically pleasing, although it is not as strict. "It has a circular subway line that is actually circle-shaped, rather than rectangular as our program would make it. I like that very much." Just as Nöllenburg und Wolff improved their program step by step, so too does the program now work step by step to produce a beautiful map. An initial sketch can be produced in just a few seconds, but it takes the computer a few more minutes or even hours – depending on how much time the scientists allow it – to calculate a more sophisticated solution.

However, the computer cannot manage any map all on its own, and it can only design medium-sized networks. "But that provides a good starting point for graphic designers," argues Nöllenburg. "A great deal of work would still be needed to create the right product from the underlying prototypes. So far this is not something network operators want to invest in." If the British psychologist Roberts had his way, the maps would continue to be designed by hand. He is particularly >

"I commute every day between Heidelberg and Karlsruhe. There are many unnecessary kinks in the line on the S-Bahn (subway) map. It does annoy me a bit," says Martin Nöllenburg.

Four years ago, IT expert Alexander Wolff began working with Martin Nöllenburg on a program for developing subway maps.

The Man Who Revolutionized the "Tube"

It was the Englishman Henry C. Beck who invented the subway map as we know it. The man who revolutionized the London Underground map and influenced transport line diagrams all over the world was unemployed at the time. A technical draftsman, Henry Beck was employed by the London Underground at various times before being once again made redundant in 1931. But for his part, the 29-year-old did not let go of the London Underground. He was in the habit of referring disparagingly to the confusing lines that became jumbled up in London's city center as "vermicelli." Then he was gripped by an exciting idea: "I looked at the old map of the underground network, and realized that it could be simplified by straightening the lines, experimenting with diagonals, and standardizing the gaps between the stations." The result was a diagram with vertical, horizontal and diagonal lines – much clearer and easier to understand. However, it was initially too revolutionary for the managers of the London Underground. A year later, Beck tried again – and this time with success: His map was printed in 1933. But Londoners didn't just use his diagram, they came to love it. For his design and the month's work it had taken, Beck received precisely 10.50 British pounds, or the equivalent of 1,000 euros in today's money. But he still wasn't offered a permanent position. Nonetheless, he became increasingly absorbed in working on the detail of his map. Today he is remembered as a great designer; in a BBC program, his diagram was selected by the British public as the second most important design icon after Concorde.

critical of the rules that lie behind the program: "These straight lines and 45-degree diagonals are simply not suited to every subway network. In London the distortions are too great, and this is something people already moan about." Instead, reckons Roberts, the rules should be adjusted for each city network. "And that's something the computer would struggle with."

Roberts himself draws subway maps, taking a whole week for the London tube network, for example. The result is a contoured picture with arc-shaped lines. In the psychologist's view, these are more readily comprehensible, an opinion he has subjected to empirical testing. Using his map, test subjects found their way around the complex Paris Metro network 30 percent quicker than with the official map. In London's tube network too, test subjects navigated 20 percent quicker.

How People View the World

Roberts has been a London Underground enthusiast from an early age. "I was totally fascinated by it as a child. All those escalators, tunnels, trains! There's surely nothing more exciting you can experience as a child in London than riding on the tube."

The University of Essex psychologist currently grapples with the issue of how people understand the world and solve problems. And this is why badly drawn subway maps irritate him: "A good map should help people to understand the world. It should relieve them of a cumbersome step in the process of calculation." By contrast, many maps actually confuse the reader. "I've yet to clap eyes on a map that I haven't wanted to improve." His new contoured diagram of London's tube network has already been incorporated into a few travel guides, but London Underground itself simply doesn't want to know, admits Roberts. "They don't like outsiders meddling in their business."

But perhaps it's not bureaucracy alone that is at fault if his plan is not hitting home. In tests, even Roberts himself has had to cede that test subjects do not always prefer the simplest maps, sometimes indeed preferring maps that are difficult to read. "Unfortunately, people will not use a map that they don't like," says the psychologist. And what test subjects liked most was what they knew – their old linear map with its neat angles. <

Photos: Ralf Barthelmes | Nadja Tempest