CITY PULSE: REVEALING CITY IDENTITY THROUGH ABSTRACTION OF METRO LINES

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Abstract

Metro systems are the pulsing veins of cities, traversing the city's texture and preserving the memory of urban life. Visualizing invisible urban metro landscape makes each city's unique identity and development more emblematic. In this project, we introduce an abstraction method that encodes metro routes as lines, cities as squares, and the global map as an abstract representation. Along with the implementation of an interactive system, the project enables a comprehensive visual exploration of the global metro lines. Through this highly abstract and minimalist form, each city's structure, symbolic identity, and regional development are revealed. Moreover, the colorful global metro map efficiently portrays the diversity and evolution of metro lines worldwide. With this pictorial we narrate the design process and our reflections along the project.

Keywords

Global Metro Lines; Urban Landscape; Abstract Art; Diverse Cities; Interactive Data Visualization.

Introduction

The lifeline of regional development has been intertwined with transportation[1]. The metro, as an increasingly important mode of transportation, connects the city's infrastructures and carries the urban memories. It has gradually evolved into a medium that conveys the city's distinctiveness and diversity while also stimulating cultural, economic and social exchanges[2].

The demand for urban development has driven the construction of metro lines. These lines facilitate population movement, enhance internal circulation, and connect impoverished with affluent areas[3]. Concurrently, metro lines contribute to a vibrant urban tapestry by connecting various locations and fostering social integration[3]. Across the globe, metro lines act as pulses, shaping the character of cities and enhancing the power of time and space to create diverse urban landscape.

We recognize that the metro system embodies the power of representing a city's uniqueness. As a transportation system, it embodies both geographical landscapes and urban culture, reflecting concentrated societal factors[4]. Beyond being a mere mode of transit, it preserves the memories of countless residents and provides insights into the city's structure, style, and culture. Visualizing this invisible urban landscape created by the metro is emblematic.

This project aims to creatively visualize metro lines in cities around the world. It explicitly portrays the implicit historical growth and regional characteristics of each city in a minimalist manner. Drawing on the concept of geometric abstract art, we adopt a
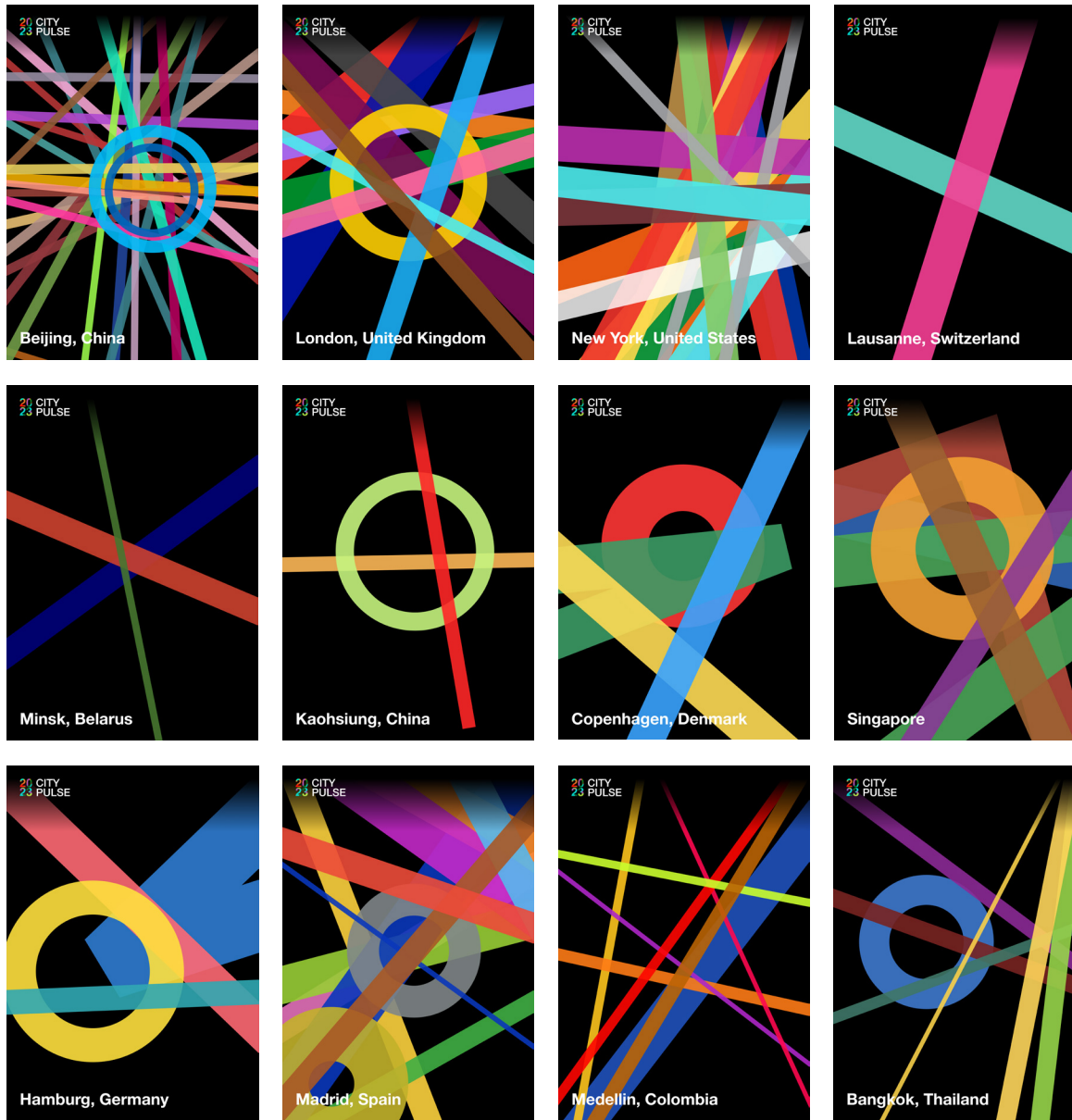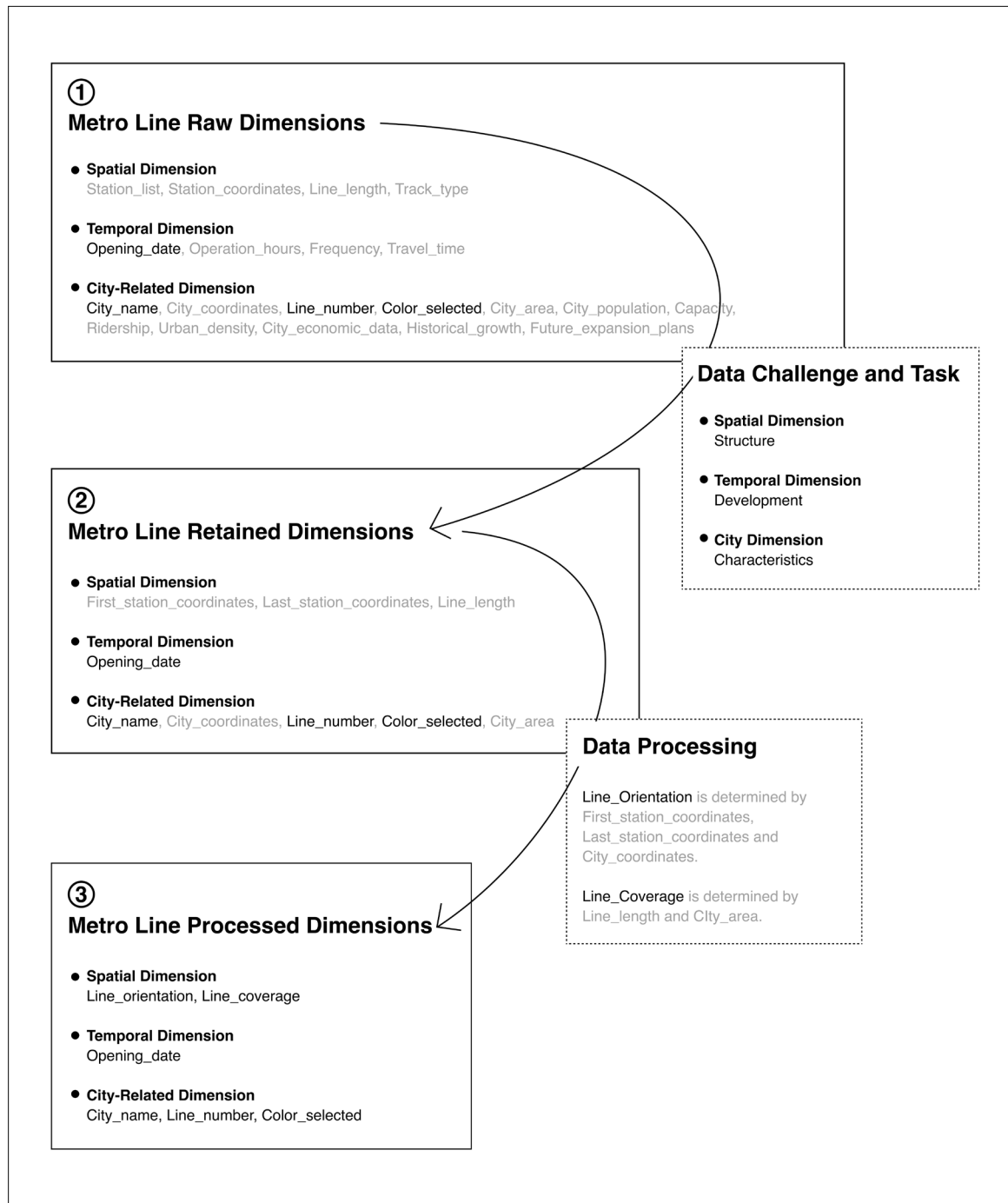
Visualizing urban landscape created by the metro

neutral, unbiased approach that inherently includes diversity through its very abstraction, maximizing information transmission within a complex dataset with minimal space[5].

An abstract symbolic form is created by transforming essential line information, where the routes are encoded as lines and cities as squares. Abstraction turns a source thing into a less concrete sign thing[6]. This approach presents the data objectively, revealing the characteristics of each city clearly and efficiently, while preserving the overall form of the metro lines. An interactive system with an abstract map layout, temporal narrative, and artistic elements is designed and implemented to facilitate exploration of the metros worldwide.

By graphically transforming complex metro data into visual symbols, this project effectively abstracts the information and enhances the characteristics associated with each line and region, revealing the hidden landscape and offers new perspectives. By lowering the comprehension barriers, the project allows all viewers to easily gain insights into metro structures and developments. Additionally, the abstract art makes complex information more visually appealing and accessible, intensifying the visual effect and the viewer's aesthetic experience. We recognize the importance of artistic and abstract methods and highlight their potential in visualization.

In this pictorial, we reflect on the whole design process in an order of data challenge, task extraction, design decision, system implemention and insights.

① **Metro Line Raw Dimensions**

- **Spatial Dimension**
  Station_list, Station_coordinates, Line_length, Track_type

- **Temporal Dimension**
  Opening_date, Operation_hours, Frequency, Travel_time

- **City-Related Dimension**
  City_name, City_coordinates, Line_number, Color_selected, City_area, City_population, Capacity, Ridership, Urban_density, City_economic_data, Historical_growth, Future_expansion_plans

Data Challenge and Task

- **Spatial Dimension**
  Structure

- **Temporal Dimension**
  Development

- **City Dimension**
  Characteristics

② **Metro Line Retained Dimensions**

- **Spatial Dimension**
  First_station_coordinates, Last_station_coordinates, Line_length

- **Temporal Dimension**
  Opening_date

- **City-Related Dimension**
  City_name, City_coordinates, Line_number, Color_selected, City_area

Data Processing

Line_Orientation is determined by First_station_coordinates, Last_station_coordinates and City_coordinates.

Line_Coverage is determined by Line_length and City_area.

③ **Metro Line Processed Dimensions**

- **Spatial Dimension**
  Line_orientation, Line_coverage

- **Temporal Dimension**
  Opening_date

- **City-Related Dimension**
  City_name, Line_number, Color_selected

Data Collection and Data Challenge

We collected and parsed data on 873 metro lines spanning 213 cities over the period from 1863 to 2023, sourced from Wikipedia[7], ensuring each record was manually checked and confirmed for accuracy. The coordinates for the stations and cities were acquired using the Google Maps API [8]. The colors were manually extracted from the real metro map.

Three main challenges exist within metro data. The spatial dimension results in unique shapes for each line and distinct structure for each region, with data covering intrinsic dimensions such as multiple station stops and geographical coordinates. The temporal dimension implies that each region's structure is in a state of evolution, with the lines dynamically updating over time. Further, the interplay between metros, population flow, and economic development across different time and space contributes to social complexity. In addressing the spatiotemporal challenge of metro systems, we find the topological structure of metro network serves as a microcosm of a city's distinctive feature, and each additional metro line serves as a record of the city's development and changes.

Design Tasks

Based on the above, the tasks are defined as follows: spatially depict the metro distribution of the city and temporally show the evolution of the metro, thereby revealing the structure and development across different periods in different regions.

Previously, metro maps were incredibly complex and challenging to decipher. In 1933 Harry Beck introduced the concept of octolinearity to abstract each line, boldly removing extraneous details that might overwhelm people with information[9]. However, as the image illustrates, the lines are thin with numerous bends and details, and the characteristics are not emphasized due to the demand for practicality. Consequently, directly piecing together these maps provides limited insights into their structural and stylistic characteristics. A more intuitive and emblematic design is needed.

Beijing	New York	Paris
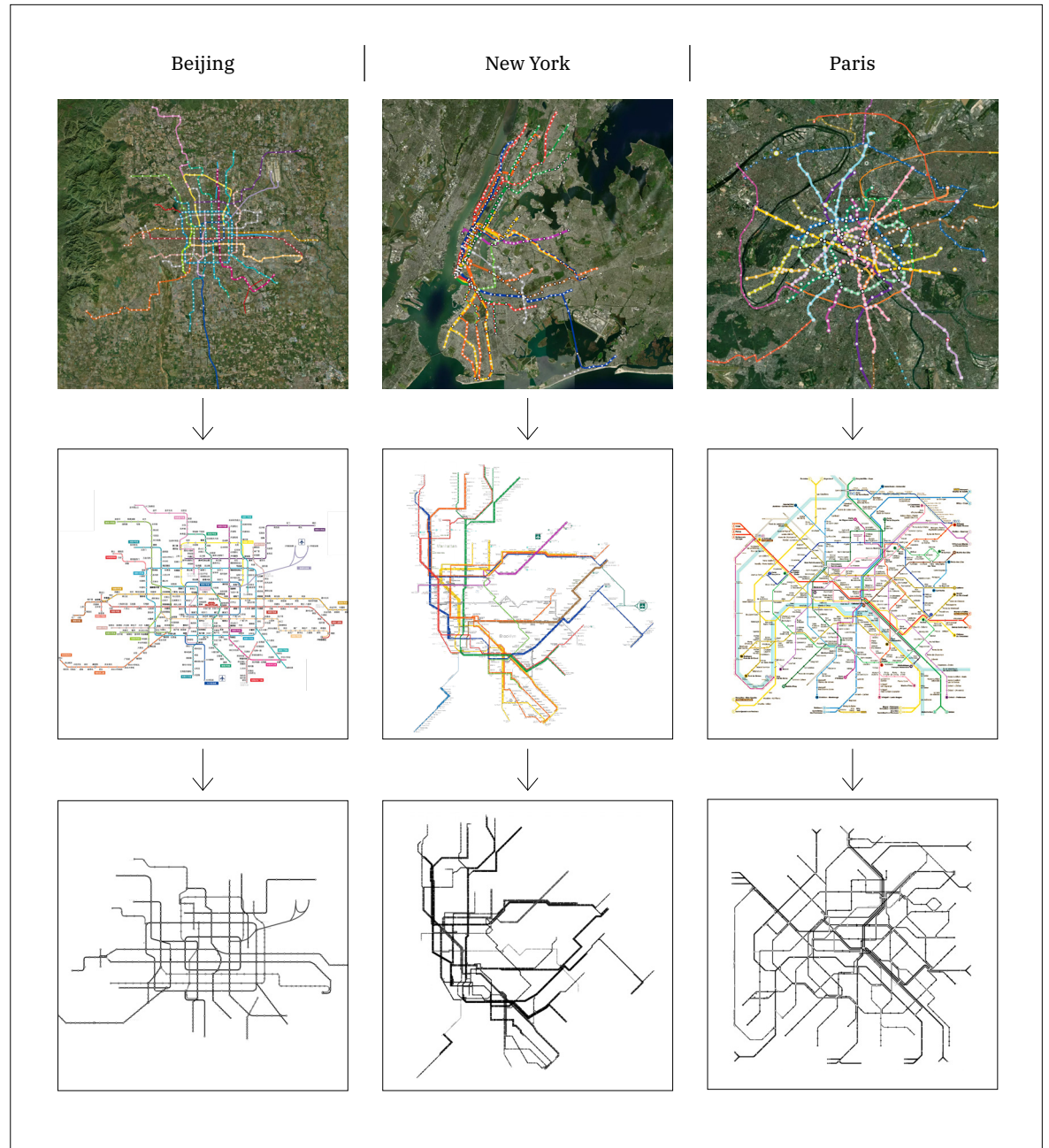
Piecing together metro maps offers limited insights into cities's structural and stylistic features.

Design Process

The abstract conveys the essential meaning[10] and determines which aspects of the source thing should be preserved in its sign thing and which should be suppressed[6] . This approach offers insights into simplifying complex systems, revealing the essence of forms, and enhancing clarity which informed our approach to distilling the key elements of the metro line's identity in an simplified and reasonable way. We selected the city it belongs to, the orientation of the line, the coverage rate, the opening date, and the line color as the final dimensions to be retained.

Inspiration from geometric abstract art
Geometric abstraction emerges from and transcends reality[11]. Malevich held that shapes and colors in a painting always communicate, emphasizing their supremacy in art over representation or narrative. Mondrian isolated and recreated the material world using minimalist forms and colors, aiming to express the potential of simple visual elements and their relationships[12].They employed abstract shapes as a visual means of artistic expression, and the objects were represented through collection of simpler geometric primitives[6]. At their best,

graphics serve as instruments for reasoning about quantitative information[5], where both abstract art and information visualization share a commonality in their utilization of abstract shapes. This exploration of geometric shapes, colors, and abstract expressions provides valuable inspiration and methods for the visual presentation of modern urban information by transforming it into simple geometric shapes with symbolic meanings.

A section of Suprematist works by Kazimir Malevich exhibited for the first time.
1914

Kazimir Malevich
Surematist Compositon:Airplane Flying.
1915
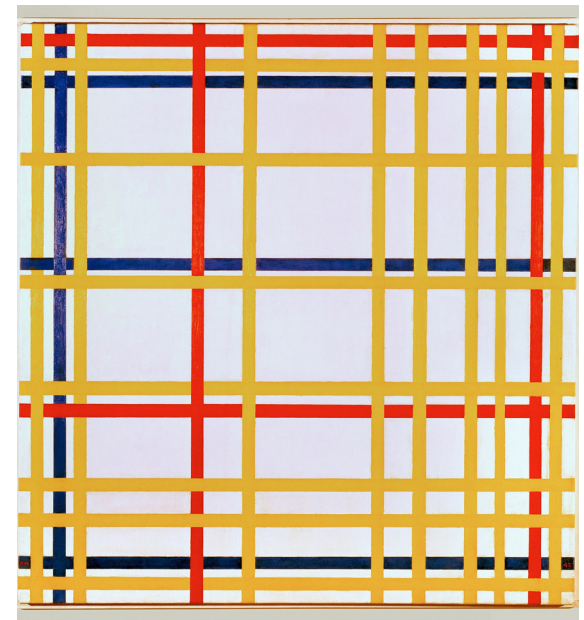
Piet Mondrian
Tableau 3, with OrangeRed, Yellow, Black, Blue, and Cray.
1921

Each city is encoded by a square.

Encoding process
· Metro lines abstraction
To simplify, we straightened the lines, changing from exact positioning to approximate orientation. Each line's orientation is determined by three points: the city center and the two terminal stations, and extends to the edges of the square. The line thickness encodes coverage, with thicker lines representing a higher proportion of city accessibility. The lines are set to appear dynamically, linked to a proposed timeline.

Locating the farthest metro line
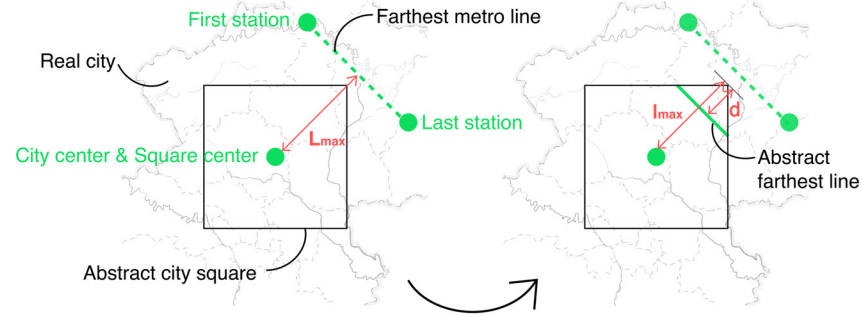
L : True line length
l : Abstract line length
d : Setting the distance of a segment from the border

First station — Farthest metro line
Real city
l_{max} d
City center & Square center L_{max} Last station
Abstract farthest line
Abstract city square

Formulas

$$\frac{l_{max} - d}{L_{max}} = \text{Line scaling}$$

Other metro lines
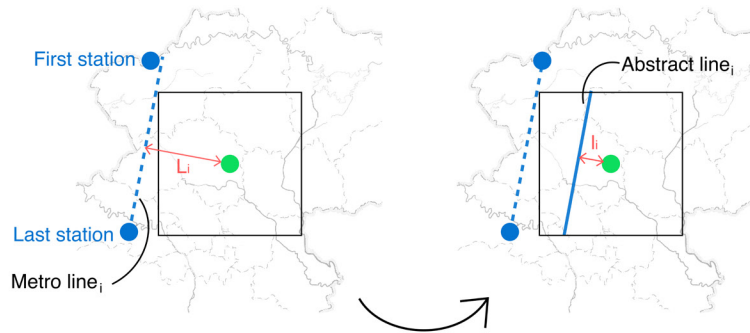
L_i : Other real metro line length
l_i : Other abstract line length

First station   Abstract line$_i$
L_i l_i
Last station
Metro line$_i$

Formulas

$$\frac{l_i}{L_i} = \frac{l_{max} - d}{L_{max}}$$

$$\downarrow$$

$$l_i = \frac{l_{max} - d}{L_{max}} \times L_i$$

Line coverage
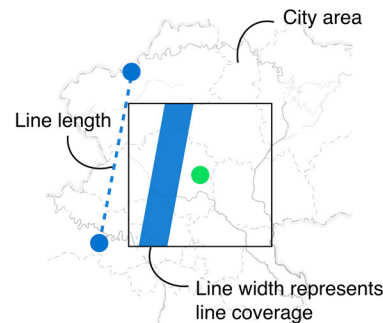
i : The i-th line
j : The j-th line
r : Average coverage radius of metro stations

City area
Line length
Line width represents line coverage

Formulas

1. Calculation of coverage

$$\text{Coverage}_{i,j} = \text{Line\_length}_{i,j} \times \frac{r}{\text{City\_area}_j}$$

2. Normalization process

$$\text{Normalized\_coverage}_{i,j} = \frac{\text{Coverage}_{i,j} - \min(\text{Coverage}_k)}{\max(\text{Coverage}_m) - \min(\text{Coverage}_k)}$$

We further encoded the circular lines as circles and lines with significant curvature as polylines.
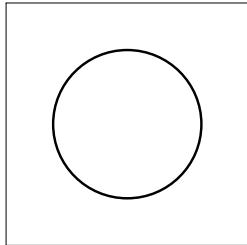
In this version, the lines are combined into cities, and the cities into a country, with all lines in black and 'special' lines highlighted in pink.
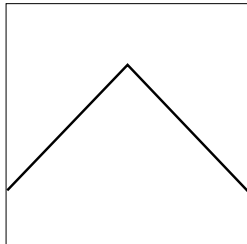
Line shape visualization
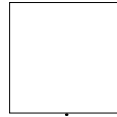
1. Linear Metro Line
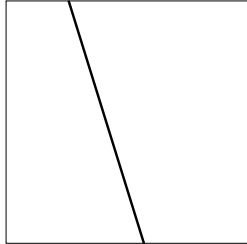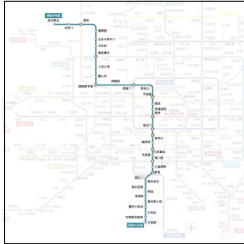
2. Circular Metro Line

3. Poly Metro Line

A trial-and-error process
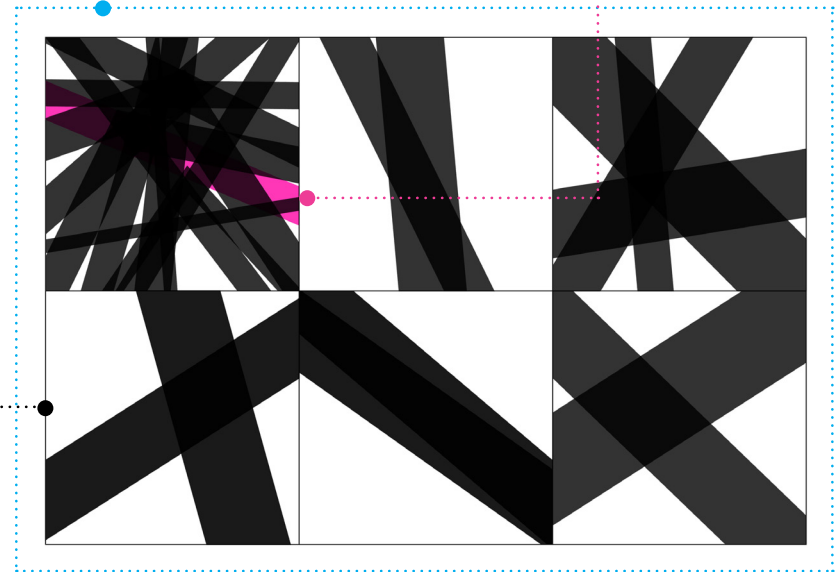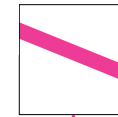An attempt to piece together a country with city squares

City:

Toulouse, France

Country:

France

Paris	Marseille	Lyon
Toulouse	Lille	Rennes

Special line:

First metro line in France

· **City squares abstraction**

Due to varying national contexts, constructing countries using city squares would be inefficient and redundant. Therefore, to maximize effective information presentation in a neat and concise manner, we retained only the city squares, arranged them approximately based on geographical locations, to form an abstract global city map. A city-based region filtering feature is planned to supplement missing city attribution information.
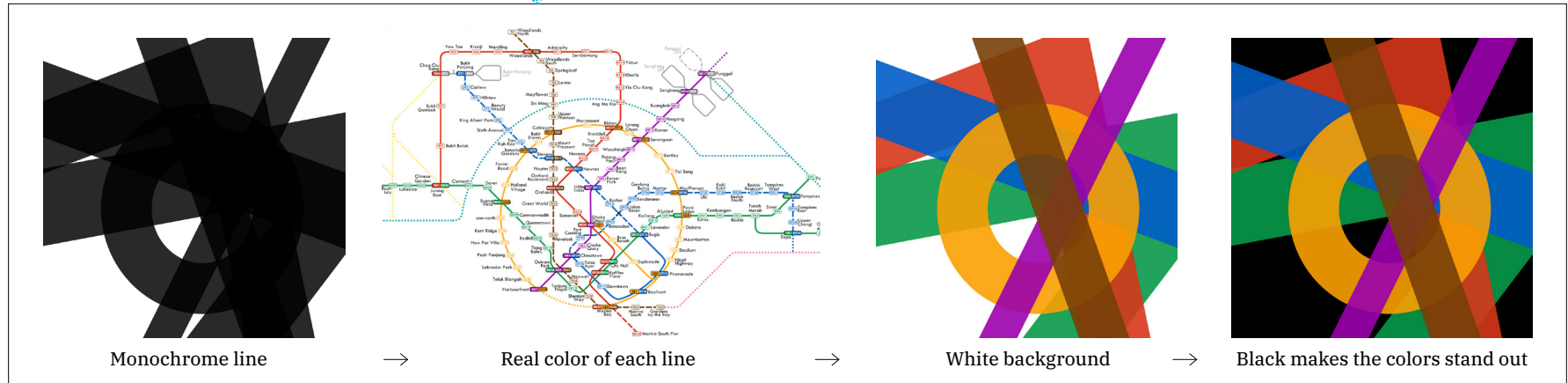
· **Color encoding**

In understanding the metro system, we realized that there are no 'special' lines—each one possesses its own uniqueness. We decided to use the colors of the real lines for color selection. Ultimately, each metro line, abstracted by its position, coverage, and color, becomes distinctly unique. When these lines converge to form the city square and eventually an abstract map, they naturally create a chaotic and unbalanced beauty. Yet within this phenomenon of diversity emerges a balance of aesthetics.

Filter

| Continents ⌄ | Countries ⌄ | Cities ⌄ |

Abstract global city map based on geographical locations

Asia   Oceania Americas   Europe   Africa

Monochrome line → Real color of each line → White background → Black makes the colors stand out
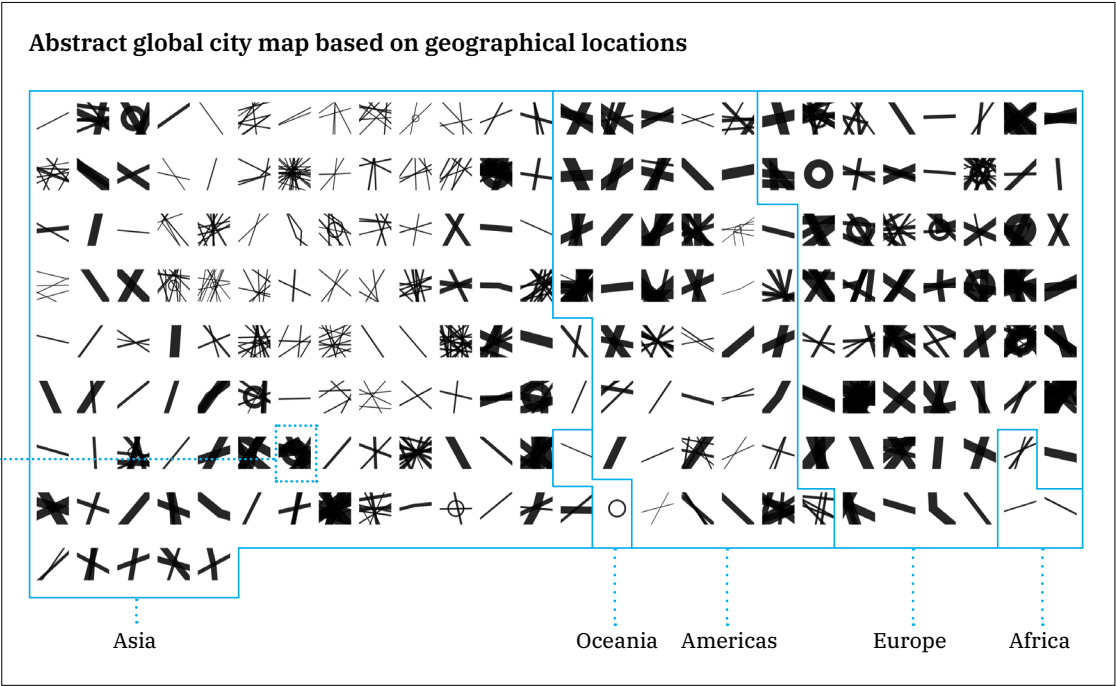
VISAP'24, Pictorials and annotated portfolios.

Timeline

Filter

Dynamic display of data

Monochrome mode

Legend

Global Metro Line Development History

In 2023, 873 metro lines were built in 213 cities.

Line Layout

Linear Metro Line
Circular Metro Line
Poly Metro Line
The line thickness represents the line coverage

Line Color

The line colors are selects from the city's own metro map

All Continents

All Countries

All Cities

Color Mode

Construction Time (Years)

1880   1900   1920   1940   1960   1980   2000   2020

Accessible from: globalmetro.github.io/city_pulse/

City Pulse System

We design and implement a system to narrate the story of global metro lines development, integrating considerations of information dissemination, interactive design, and aesthetic experience.

Interaction design

The system is built with Vue.js, and the 213 city squares and 873 metro lines are visualized using D3.js. The overview and single city options allow for flexible moving between the world holistic map and particular city maps. The interactive timeline allows viewers to flexibly control time from 1863 to the present. The filter highlights selected continents, countries, or cities in color, while the rest are rendered in white, focusing attention on the chosen area and its color choice. Viewers can freely select their time and region of interest to gain knowledge and insights. A monochromatic toggle button is designed to offer the same visual impact for color-blind viewers.

Visual design

We employed minimalist graphic design and reverse type to communicate a sense of industry and speed. The filter box, timeline, buttons, and icons in the interface are drawn concisely. Clear fonts, graphs, and layouts only keep the reasonable and functional features to maintain the correctness and usability of visual information.

The interface design leverages Gestalt principles, where the principle of closure
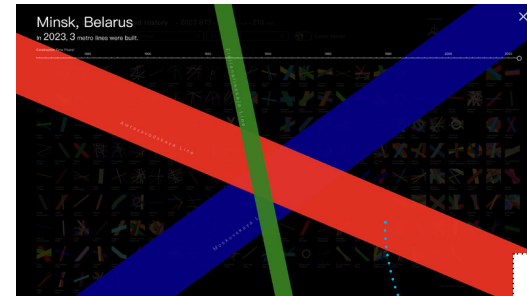
Interaction Design

Filter
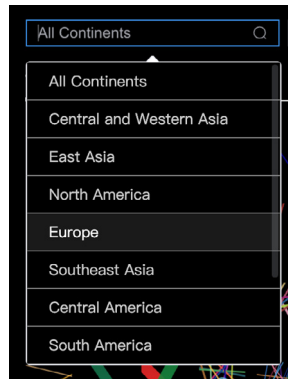
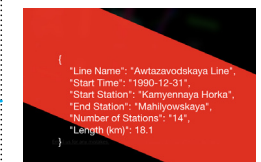Unchoosen cities become monochrome

Filtered cities retain color
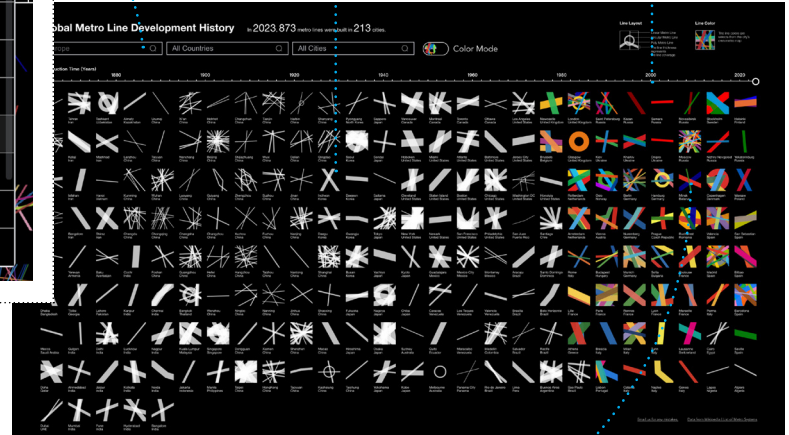
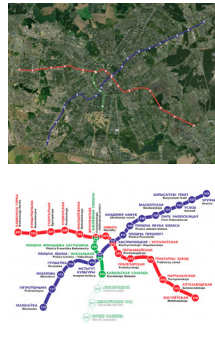Click on individual city square to access detail page.

Detail page

Minsk, Belarus
In 2023, 3 metro lines were built.

Real metro map

Metro line information

{
"Line Name": "Awtazavodskaya Line",
"Start Time": "1990-12-31",
"Start Station": "Kamyennaya Horka",
"End Station": "Mahilyowskaya",
"Number of Stations": "14",
"Length (km)": 18.1
}

Hover on a metro line to display detailed information.
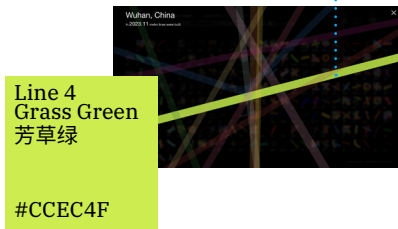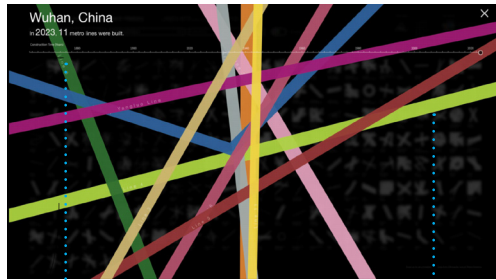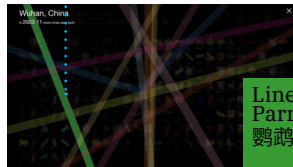
City : Wuhan, China

Line 4
Grass Green
芳草绿

#CCEC4F

Line 6
Parrot Green
鹦鹉绿

#379A33

A Tang poem about Wuhan

By sunlit river trees can be count'd one
by one, On Parrot Islet sweet green grass
grows fast and thick.
晴川历历汉阳树, 芳草萋萋鹦鹉洲。

The Yellow Crane Tower
by Cui Hao, Tang Dynasty
唐 · 崔颢《黄鹤楼》

intuitively guides our perception to form complete shapes[13]. This allows viewers to distinguish individual cities on a global map brimming with intertwined lines and colors.

Observations and Insights

The system not only showcases the uniqueness of individual cities but also juxtaposes multiple cities to reflect overall diversity. There is a natural beauty in the chaotic and unbalanced distribution of metro lines, which extends to the cities themselves.

Metro color as a reflection of a city's cultural spirit

Metros are highly industrialized products, but the connection between their colors and the cities reflects the cultural spirit. Upon coloring, we observed that each region's color selection is distinct, showcasing its unique characteristics.

Cities associated with water often have a blue line representing the water system, such as Boston Blue Line, passing under the Boston Harbor[14]. Some cities use poetic names and colors for their lines. In Wuhan, line colors like Aromatic grass green and Parrot green together reflect a classical Chinese poem related to Wuhan, "By sunlit river trees can be count'd one by one. On Parrot Islet, sweet green grass grows fast and thick," which reminds people of the pleasant scenery of a spring outing.
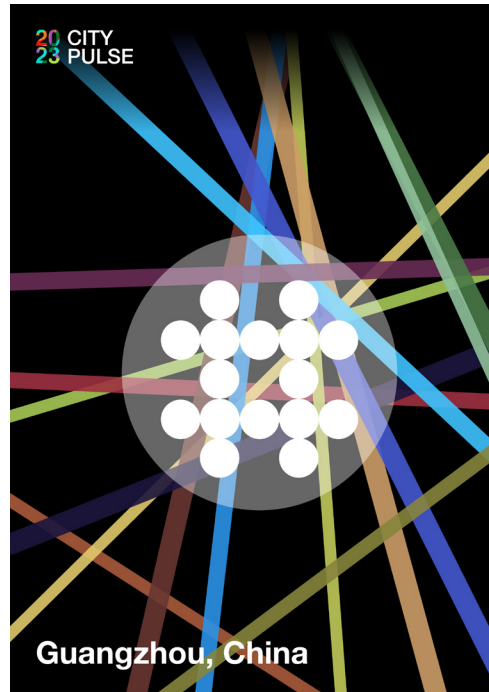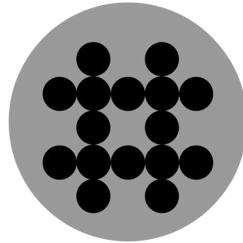
Metro structure as a city's symbolic identity

The combination of abstract lines and actual metro color schemes showcases the characteristics of each city. Cities with a single-core point structure, like Beijing and Chengdu[15], have densely packed central ring lines radiating outward. In contrast, cities with multi-core network structures[15], like Guangzhou and Dongguan, have transit lines primarily radiating outward, with the central urban area's network density slightly lower than that of single-core cities. As cities develop, metro topologies tend to become mixed[15]. Madrid's transit network is representative, with 12 main lines and one straight line in a radial network, complemented by several parallel lines, creating a mixed topology. The generalized patterns of metro lines converge to form a colorful map that resembles a city's symbolic identity.
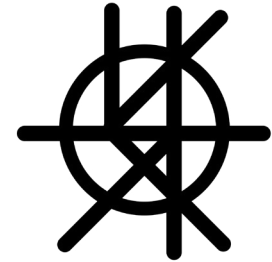
Metro structure
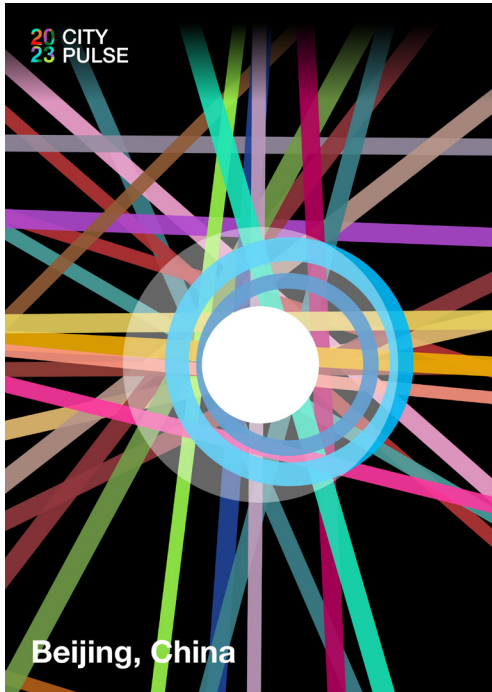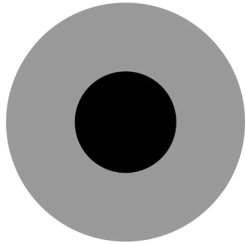
| Single-core point structure	Multi-core network structures	Mixed topology

**Metro development as a lens on global evolution**

The evolution of the metro system, from the birth of the London metro to the vast global metro networks of today, has always been closely linked to international dynamics and economic development[2]. In the early 20th century, industrialized Europe and North America, led by London, pioneered metro systems. Following the rapid economic recovery and accelerated urbanization post-World War II, cities like New York, London, Paris, and Berlin saw extensive metro construction. Over the first century since the inception of metros, significant disparities in metro system sizes exist between Asia, Africa, Central and South America, Europe and North America, influenced by the colonial era's economic impact. The imbalance between the East and the West has gradually shifted in the 21st century, with Asian countries such as China, India, and Turkey rapidly catching up with Western nations. Through juxtaposition and comparison, the project reveals the implicit global development disparities from the perspective of metro systems.

Monochrome mode allows all viewers to clearly see the changes in coverage.
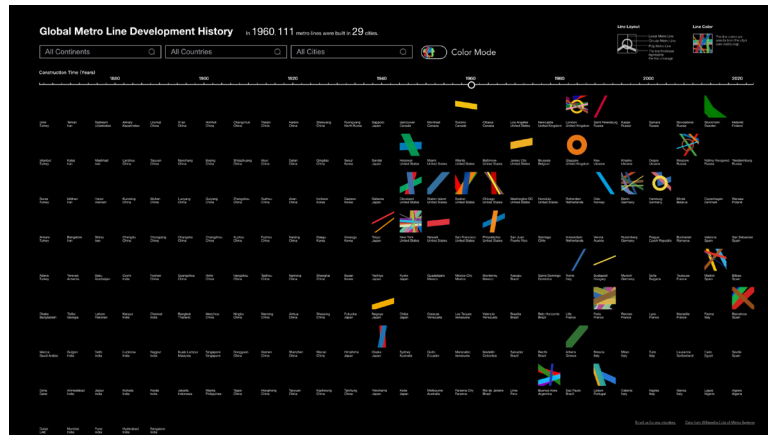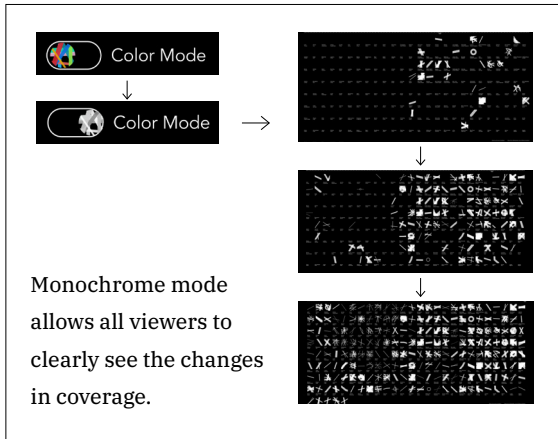
1960
Industrialized Europe and North America, led by London, pioneered metro systems.
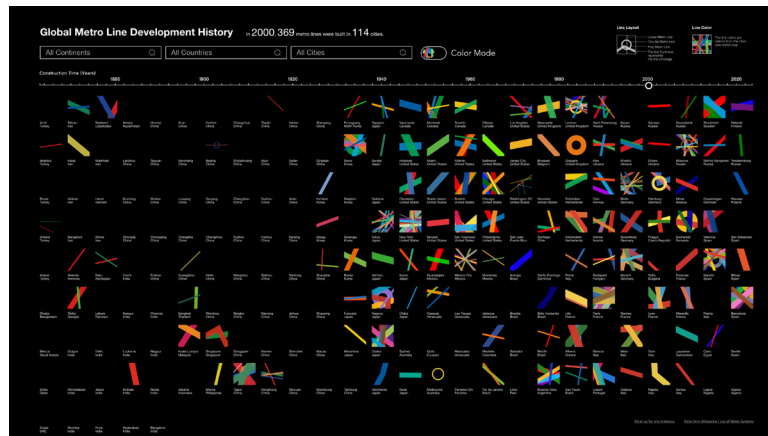
2000
Following the rapid economic recovery and accelerated urbanization post-World War II, cities like New York, London, Paris, and Berlin saw extensive metro construction.
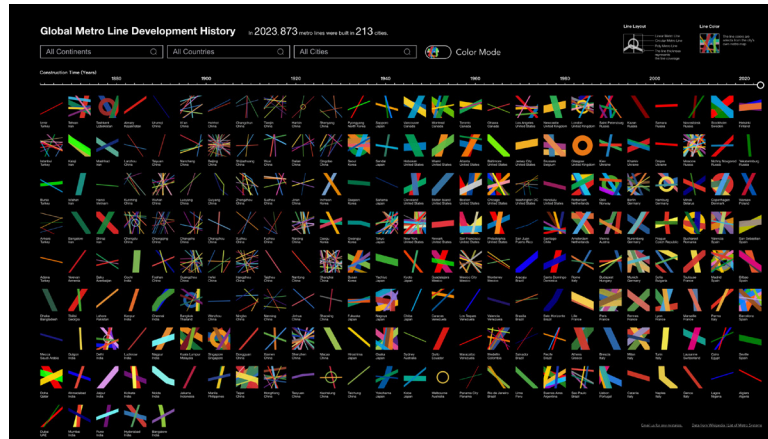
2023
The imbalance between the East and the West has gradually shifted.

Conclusion and Discussion

Employing abstract and symbolic visuals to explore the city's intricate connection with its metro system, City Pulse reveals its culture and social evolution behind the metro landscape.

An artistic urban visualization style is developed, where the metro is transformed into an abstract symbol, offering a new visual understanding of the city. This symbolic interpretation diverges from cognitive structures, enabling viewers to observe a region's characteristics and evolution from a broader perspective, transcending the metro's transport function and infusing it with cultural and artistic significance. The abstract symbolic expression alters the visual perception, allowing us to grasp and appreciate the city's complexity and distinctiveness from a fresh perspective.

Our project indicates that abstraction possesses the power to enhance the expressiveness and attractiveness of complex data. Detailing, accuracy, and comprehensiveness are not the only paths for presenting data. By condensing complex information while conveying it with visual impact, abstract art can also be an efficient method of visualization which facilite comprehension, allowing viewers from any background to better gain insights and appreciate the charm of data. The fusion of data with art provides both cognitive insights and aesthetic appeal.

Further, the visualization form of abstract art, lacking specific shapes to convey precise meanings, can create myriad styles of imagery that carry diverse concepts. By removing specific details, the abstraction is able to describe a broader range of instances[16]. This inherent inclusiveness provides the capability to display various types of data. Therefore, incorporating abstract art in visualization has the potential to showcase the kaleidoscopic space formed by the diversity of unique individuals within any category, serving as a form of equitable data aesthetics.

As the world evolves, more metro lines will be constructed, giving rise to continuous changing abstract urban landscapes. We plan to enable the system to dynamically update, keeping pace with history, and collectively construct the colorful global landscape of metro.

Acknowledgements

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