FPX-G: First Person Exploration for Graph

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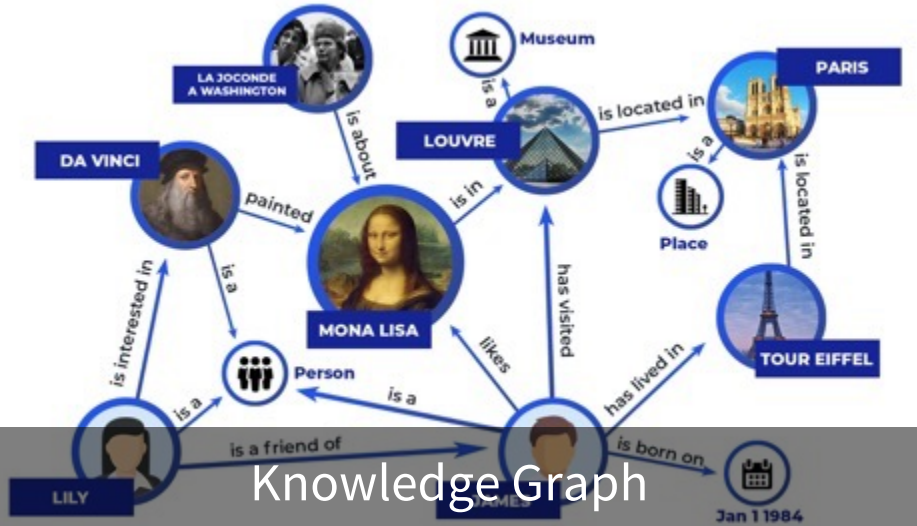
Graph: a general data structure

Graph $G = (V, E, A)$

Social Network



Knowledge Graph

Subway Network

Many others: protein-protein interaction, call graph of software, road network, etc.

Graph Search, Exploration and Visualization

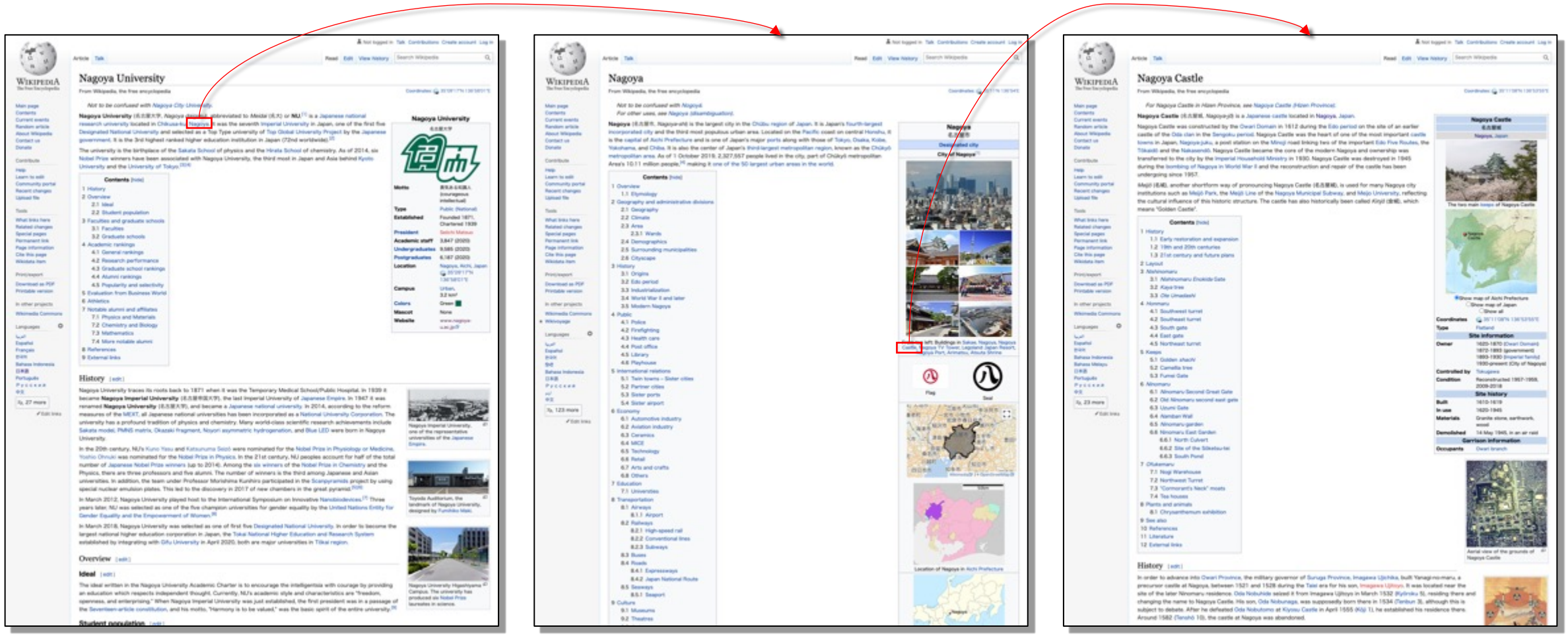
- Task: seeking information from a graph
- Graph Search
  - Given a graph query (e.g., graph pattern, keyword), find subgraphs matching to the query
  - e.g., GraphQL, SPARQL, Cypher
- Graph Exploration
  - Interactive seeking
  - Procedure (like browsing Web sites)
    - Repeat: (1) visit a vertex and (2) choose a neighbor to explore
- Graph Visualization
  - Bird-eye-view of a graph
  - e.g., Gephi, Cytoscape, Argo Lite

Good when users have clear information needs.

Good when users have unclear information needs.

Good when users want to analyze graph structures.

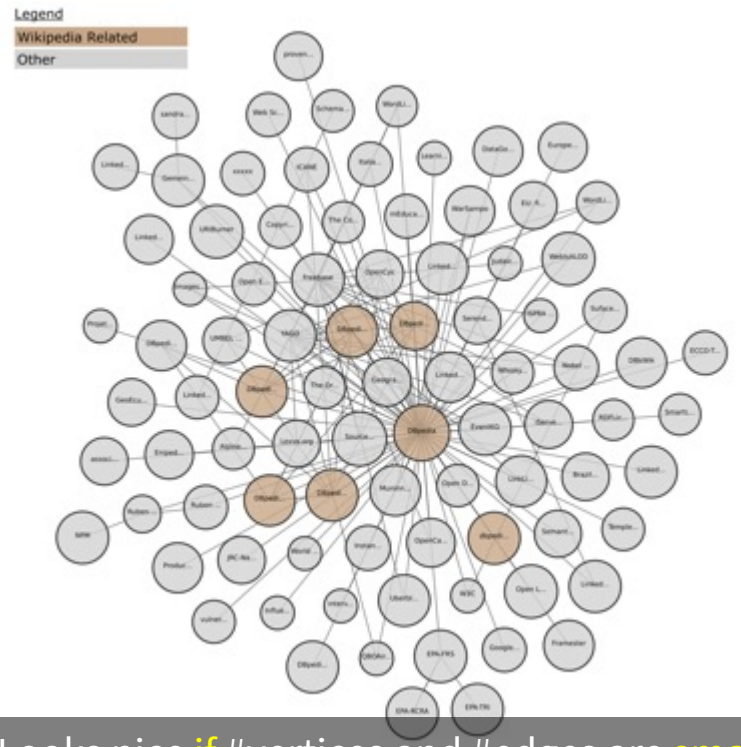
Graph Exploration: browsing approach



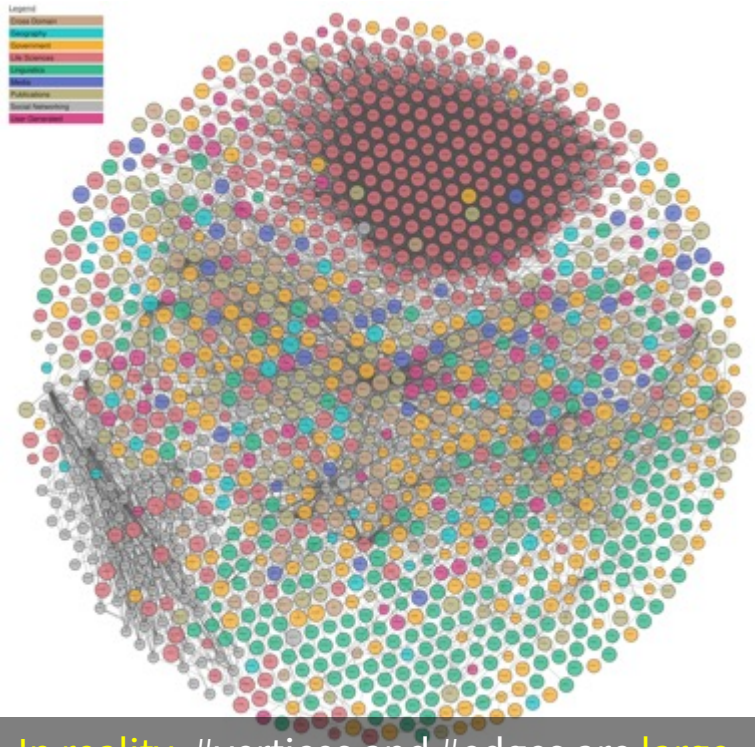
Exploration process is go-and-back the links.

Graph Visualization as an Exploration Tool

Graph visualization is mainly done in 2D space.



Looks nice if #vertices and #edges are small.



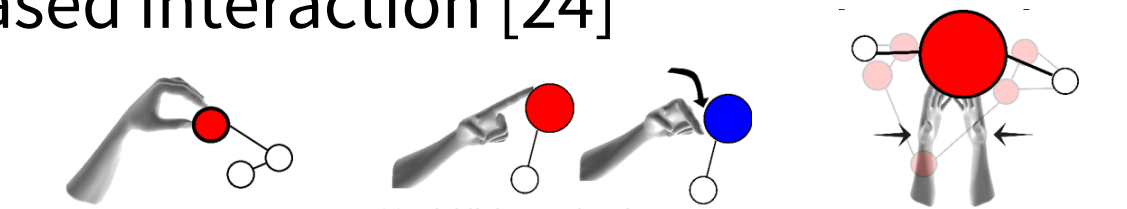
In reality, #vertices and #edges are large.

Our approach for Graph Exploration

- Drawbacks of existing approaches
  - Browsing approach
    - Neighboring vertices can be only accessible.
  - Visualization approach
    - Limitation of 2D space for visualization
      - When the size of a graph is large, visualization may not be recognizable.
- Our approach (FPX-G) utilizes 3D space.
  - Motivated to realize an approach in-between existing approaches
  - Visualizing a subgraph in 3D space
  - Vertices in some hops away can be accessible.
  - VR (virtual reality) technology
    - Users can access vertices in a walk-through manner.

Related Work: Graph + VR

- Graph visualization with gesture-based interaction [24]
  - Bird-eye-view based visualization
  - Hand gesture-based interactions: shift, highlight, rotate, and group



(a) Move a node: Use five fingers to grab the node, and can move it until release.

(c) Highlight a node: First put up the index finger, target it on the node and put it down and up back.

(g) Group: Put two palms face to face, with a little distance, then clap quickly.

Part of Fig.1 of [24]

- Dynamic graph analysis [26]
  - Bird-eye-view based visualization
  - Analysis: topological analysis
  - Interactions
    - Changing analytical views between overview and detailed
    - Changing analytical views in time axis

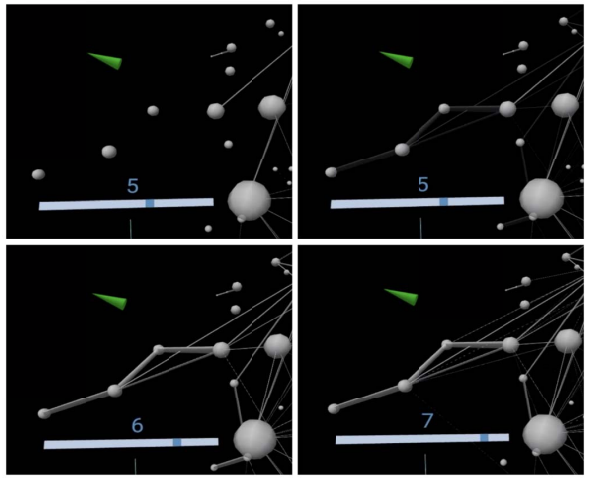
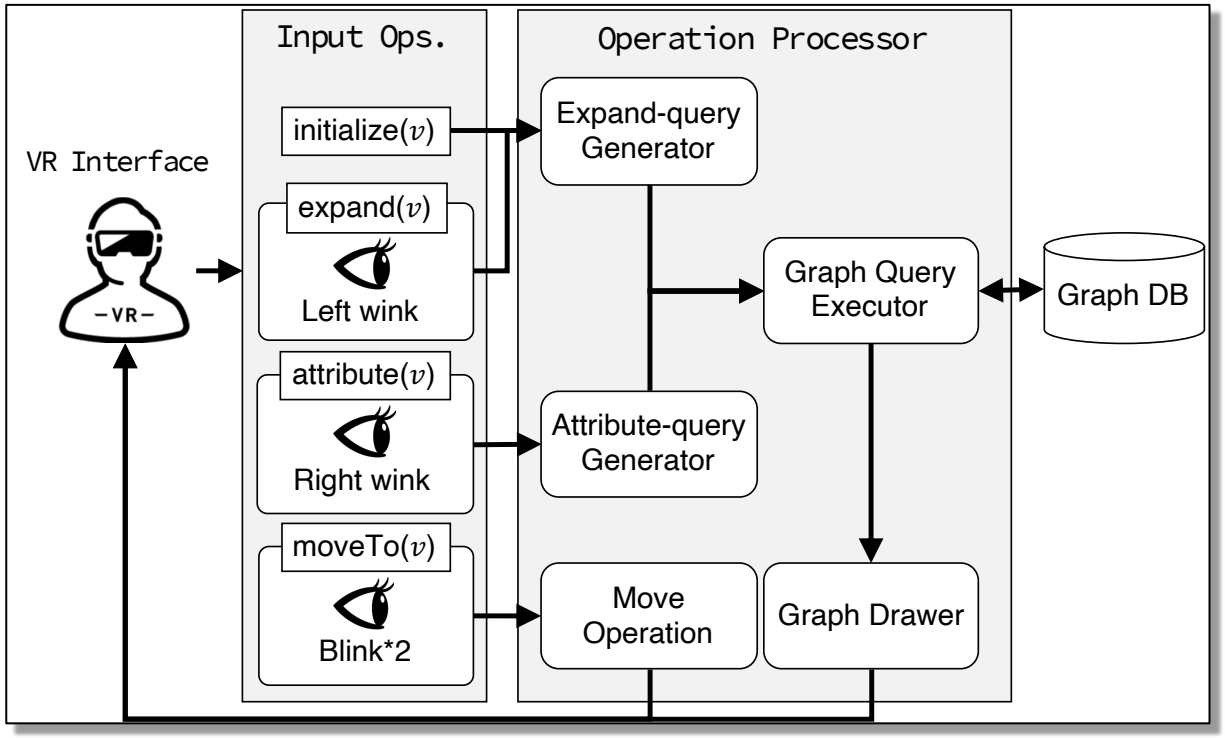


Fig.3 of [26]

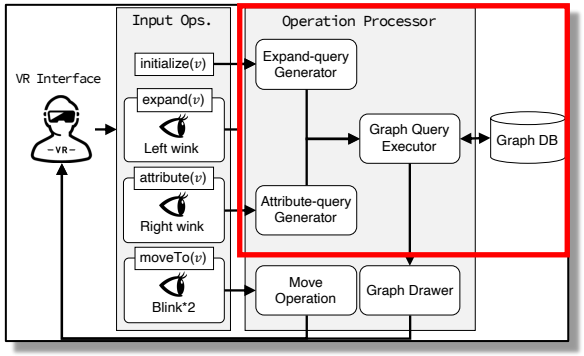
[24] Y. Huang, et al., “A Gesture System for Graph Visualization in Virtual Reality Environments,” in PacificVis17, 2017, pp. 41–45.
[26] J. Sorger, et al., “Immersive Analytics of Large Dynamic Networks via Overview and Detail Navigation,” in AIVR19, 2019, pp. 144–151.

FPX-G: our approach

- VR interface for graph exploration
  - Related works (such as [24] and [26]) focused on graph visualization and not on graph exploration.
- Graph database-based data access
  - To realize general interface
  - Two basic operations for graph
    - Expand and Attribute
- Eye-tracking based operations
- Graph drawing: Physical model
  - Spring model and electric force by the Coulomb's law



Operation/Query for Graph DB



- [Op.1] Expand: load (1) neighbor vertices and (2) edges between them

$E_1^{(e)}$

```
SELECT ?u WHERE {v ?p ?u}
```

$E_2^{(e)}$

```
SELECT ?u1 ?u2
WHERE {v ?p1 ?u1; ?p2 ?u2. ?u1 ?p3 ?u2}
```

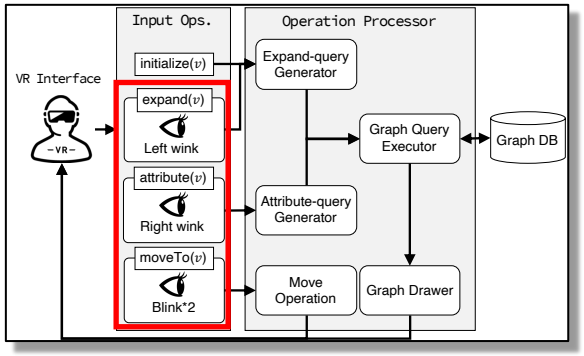
- [Op.2] Attribute: load attributes of a vertex

```
SELECT ?p ?o
WHERE {v ?p ?o. FILTER(isLiteral(?o))}
```

- Here, SPARQL Endpoint is assumed for Graph DB.
  - SPARQL Endpoint is a graph DB for RDF data.
  - Note that other queries (GraphQL and Cypher) can be used for other graph DBs.

User Interface

Operations	Controller	Eye-tracking
Vertex selection	Pointing	Gaze
Expand	Left hand Trigger	Left wink
Attribute	Right hand Trigger	Right wink
Move	Both hand Trigger	Blink*2



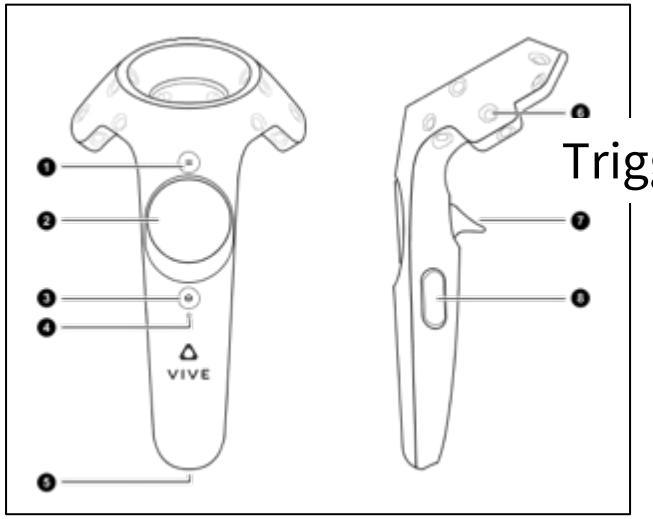


image from https://www.vive.com/eu/support/vive-pro-eye/category_howto/about-the-controllers---2018.html

- Motivation for eye tracking-based operation
  - To realize hand-free operations
  - Hands should be used for more complicated operations.
    - Keyboard inputs
    - Hand gestures proposed in [24]
      - Shift, highlight, rotate, and group
- Current implementation uses HTC VIVE Pro Eye and Unity.

[24] Y. Huang, et al., “A Gesture System for Graph Visualization in Virtual Reality Environments,” in PacificVis17, 2017, pp. 41–45.

System view (Overview and Gaze)

Attribute and Expand Operations

Attribute Operation

Right wink

Expand Operation

Left wink

Simulation-based Evaluation

- Question: *How fast users can reach a desired vertex from a user-specified starting vertex through graph exploration?*
  - Users are assumed to have no idea about the desired vertex until they reach to it.
- Evaluation metrics: the number of vertices visited during an exploration from the starting vertex to the destination vertex.
  - Sum over randomly selected 1,000 starting-destination vertex pairs.
- Comparison: FPX-G and a browsing approach
- Graph data (synthetic): 200 vertices
  - Perfect m-ary tree ($m = 5$ in this experiment)
  - Watts-Strogatz graph (small-world property)
    - Short average path length, high clustering coefficient.
  - Barabasi-Albert graph (scale-free property)
    - Degree distribution follows the power law.

User models

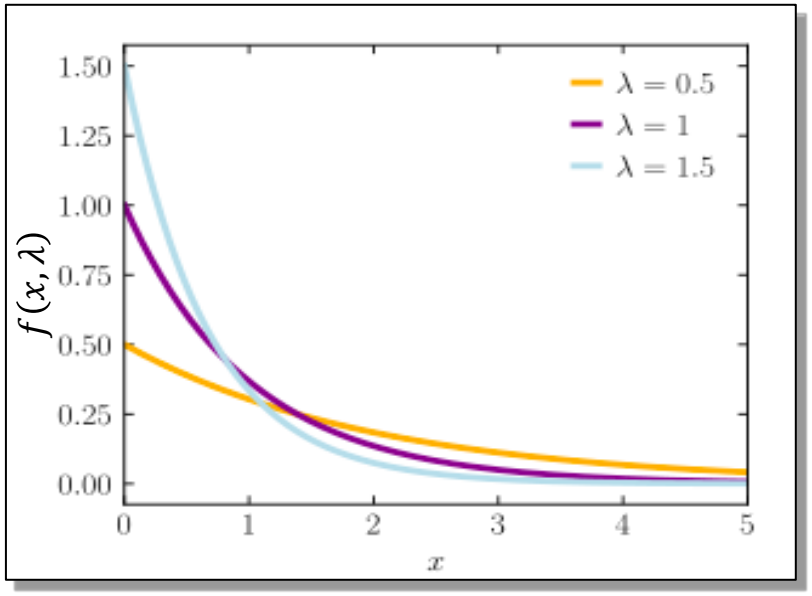
- User model in the browsing approach (2D user model)
  - Random surfer model
    - Randomly access to neighbor vertices and occasionally go back to the source vertex.
- User model in FPX-G (3D user model)
  - Basic idea: randomly access to visible vertices
  - User preference
    - Some users prefer to access near vertices
    - Some users prefer to access far vertices

  ➔This is captured by an exponential distribution.

$$f(x,\lambda) = \begin{cases} \lambda e^{-\lambda x}, & x \geq 0 \\ 0, & x < 0 \end{cases}$$

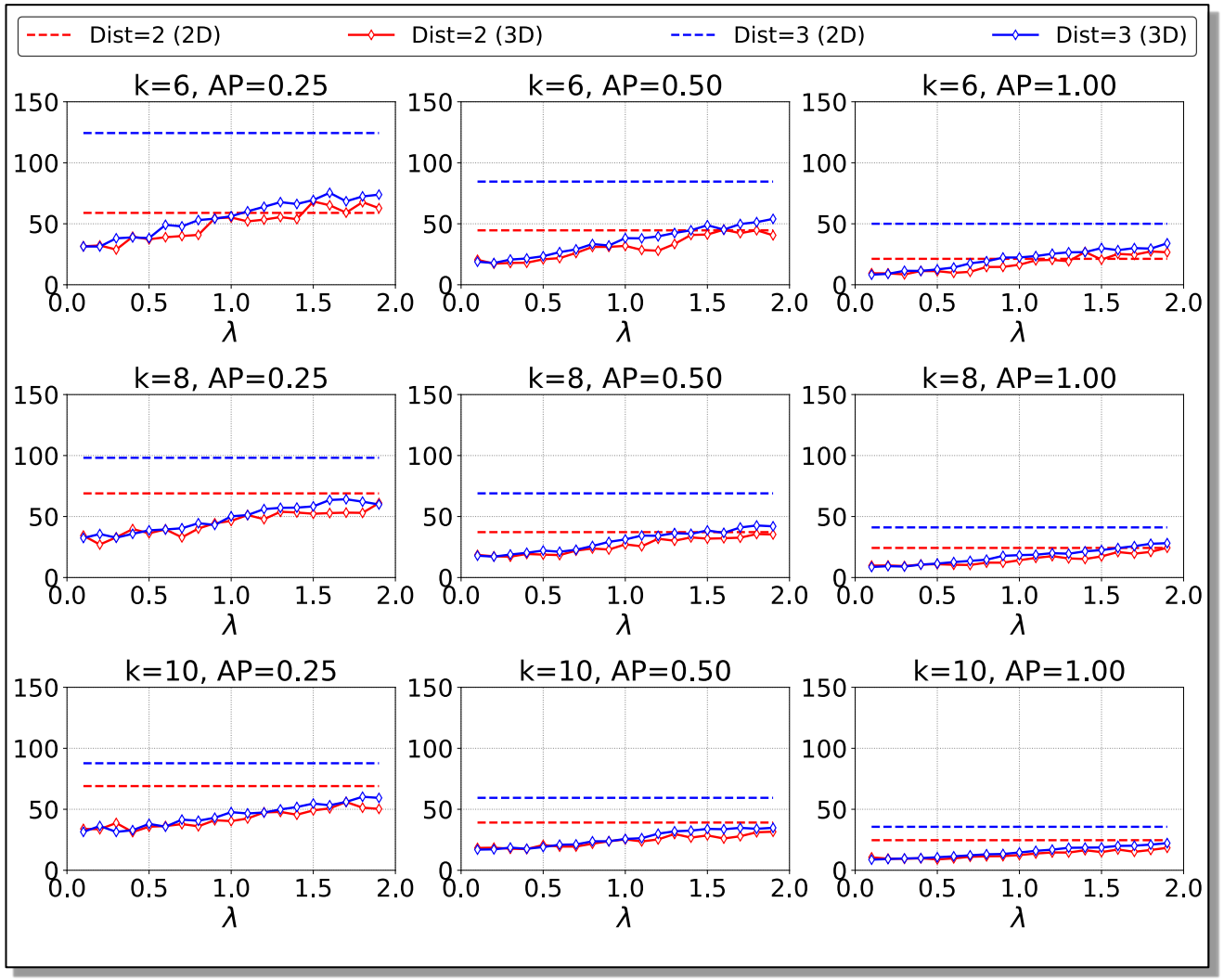
where $\lambda > 0$ is a parameter for the user preference for distance.

- Higher λ, the more users prefer closer vertices.



Result on Watts-Strogatz graph

- The larger distance from source to destination (large Dist), the larger gap between 2D and 3D user models.
- Users prefer further distance (small λ) can reach to the destination vertex faster.
- In denser graph (large k), the 3D user model is superior to the 2D user model.



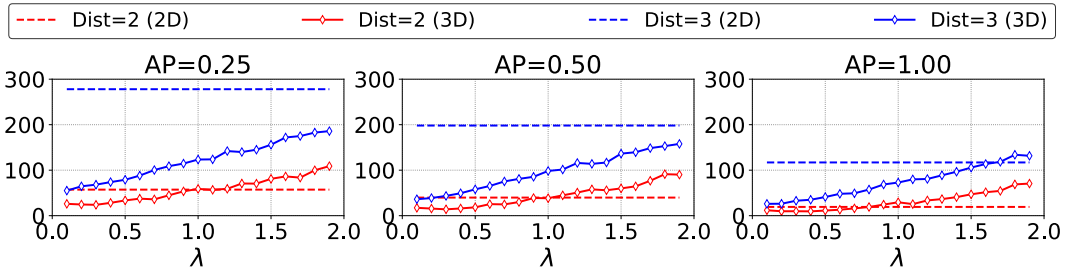
- Dist means the distance from source to destination vertices.
- k is the mean degree parameter of Watts-Strogatz model.
- AP means awareness prob. that users notice the destination.

Conclusion

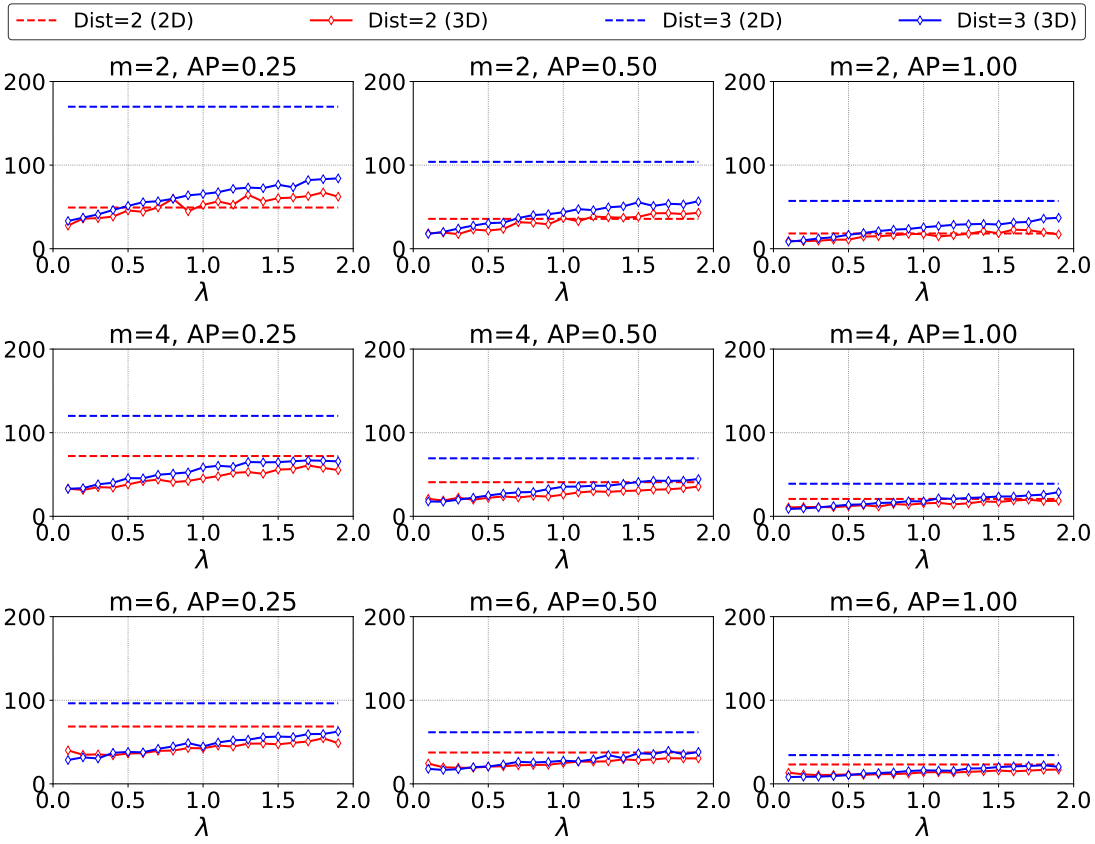
- Summary
  - FPX-G: Graph exploration using VR technology
    - Users can see vertices in several hops away from the visited vertices.
    - Demo video: https://vimeo.com/512228512
  - Simulation-based evaluation shows its superiority to the traditional approach (i.e., browsing approach).
- Future direction
  - User study (maybe after the current situation of COVID-19)
  - Improvements
    - Graph drawing in VR space
    - Interactive exploration: filtering operation during exploration
    - Other input methods for more advanced operations

Results

Perfect 5-ary tree



Barabasi-Albert graph



Watts-Strogatz graph