

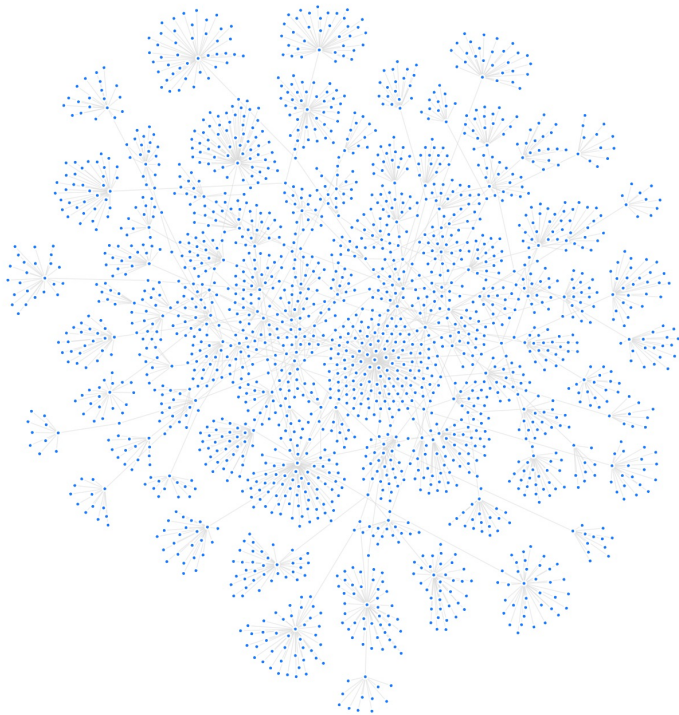
NetworkCanvas: Supporting Progressive Network Visualization Exploration via Adaptive Recommendations

Wenchao Li^{1,2}, Yuewen Gao³, Yu He³, Cong Zhu⁴, Ke Xu³



The Problem of Network Exploration

A CYBERSECURITY ANALYST



Centrality analysis?

Hunt for command-and-control servers.

Flow pattern analysis?

Detect traffic anomalies.

Community detection?

Identify botnet formations.

Thousands of IPs as nodes. Communication patterns as edges. A threat somewhere in the graph. Where to begin?

THE CORE CHALLENGE

Intricate topology and diverse attributes create an enormous exploration space.

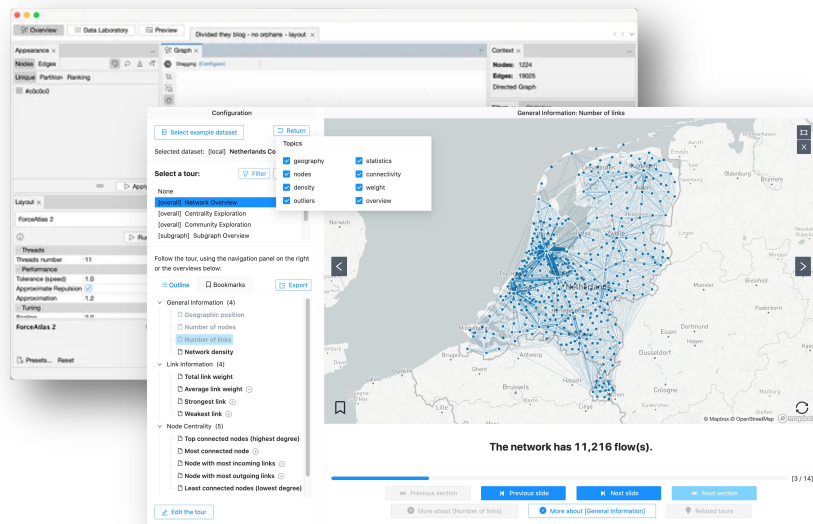
ANALYSIS PARALYSIS

For non-experts especially, users stare at the network without knowing where to start. Critical patterns are missed, not for lack of tool power but for lack of guidance.

Existing Tools Leave a Gap

Network Visualization Tools

Grephi, NetworkNarratives, ...



Powerful algorithms, but require predetermined goals and manual workflow orchestration.

Visualization Recommenders

Draco, Voyager, ...



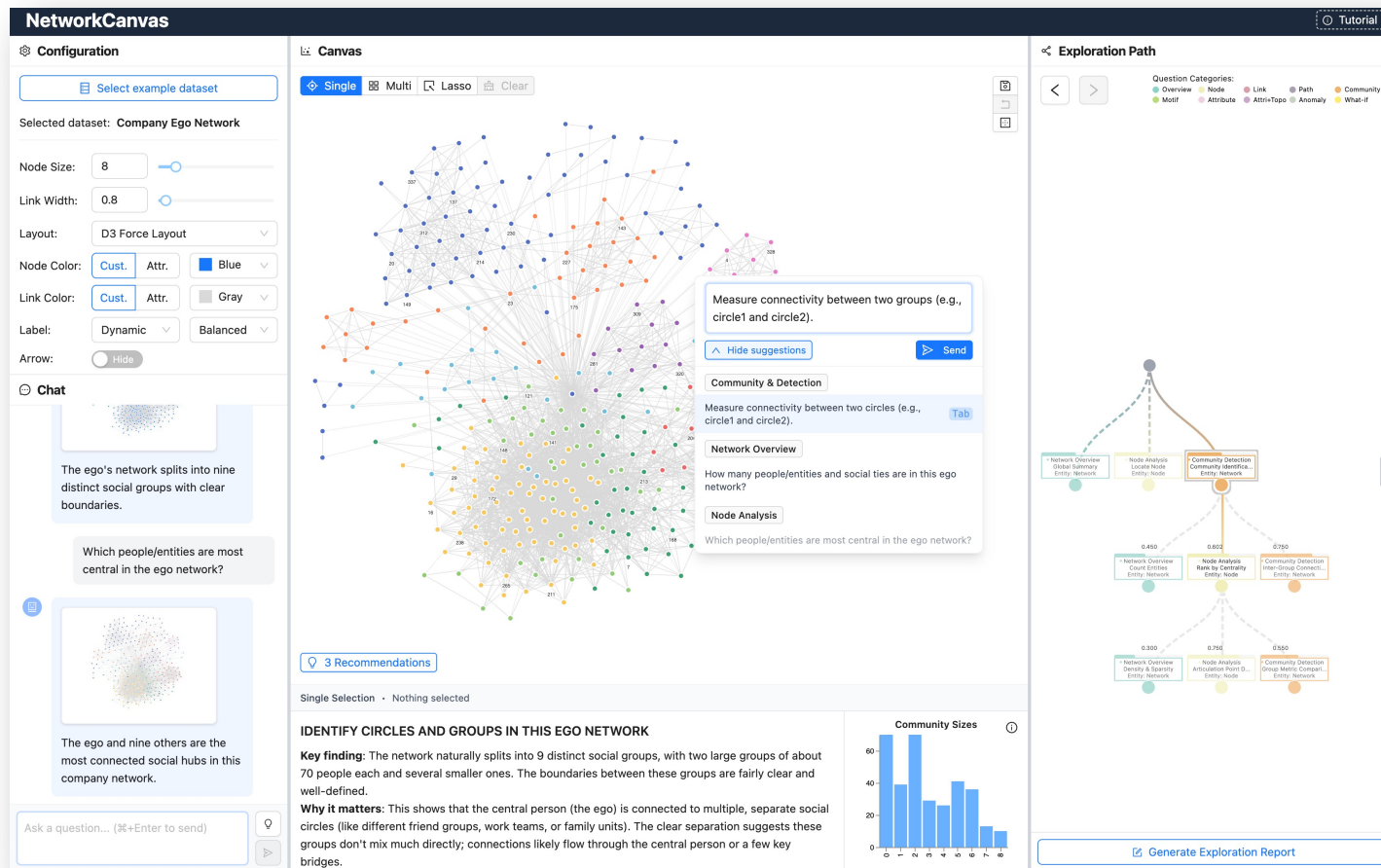
Designed for tabular data. Do not understand graph structure or network-specific questions.

THE GAP

No tool unifies adaptive guidance with network-aware provenance.

What if exploring a network
felt like a conversation,
not a scavenger hunt?

Our Approach (NetworkCanvas): Exploration as Adaptive Dialogue



CORE IDEA

Each interaction tells the system what the user cares about. The system responds with personalized suggestions for what to look at next.

Core System Modules

1. Question-Affinity Graph

QAG Engine

10 analytical question categories. A 10×10 matrix of transition weights. Learns per-user preferences from observed behavior.

2. Analytic State Graph

ASG Manager

Provenance as a branching directed acyclic graph. Each branch preserves its own context and recommendation state.

3. Feedback Interpreter

Context-Aware

Bridges low-level interactions and high-level intent. Selecting hub nodes triggers different suggestions than selecting bridges.

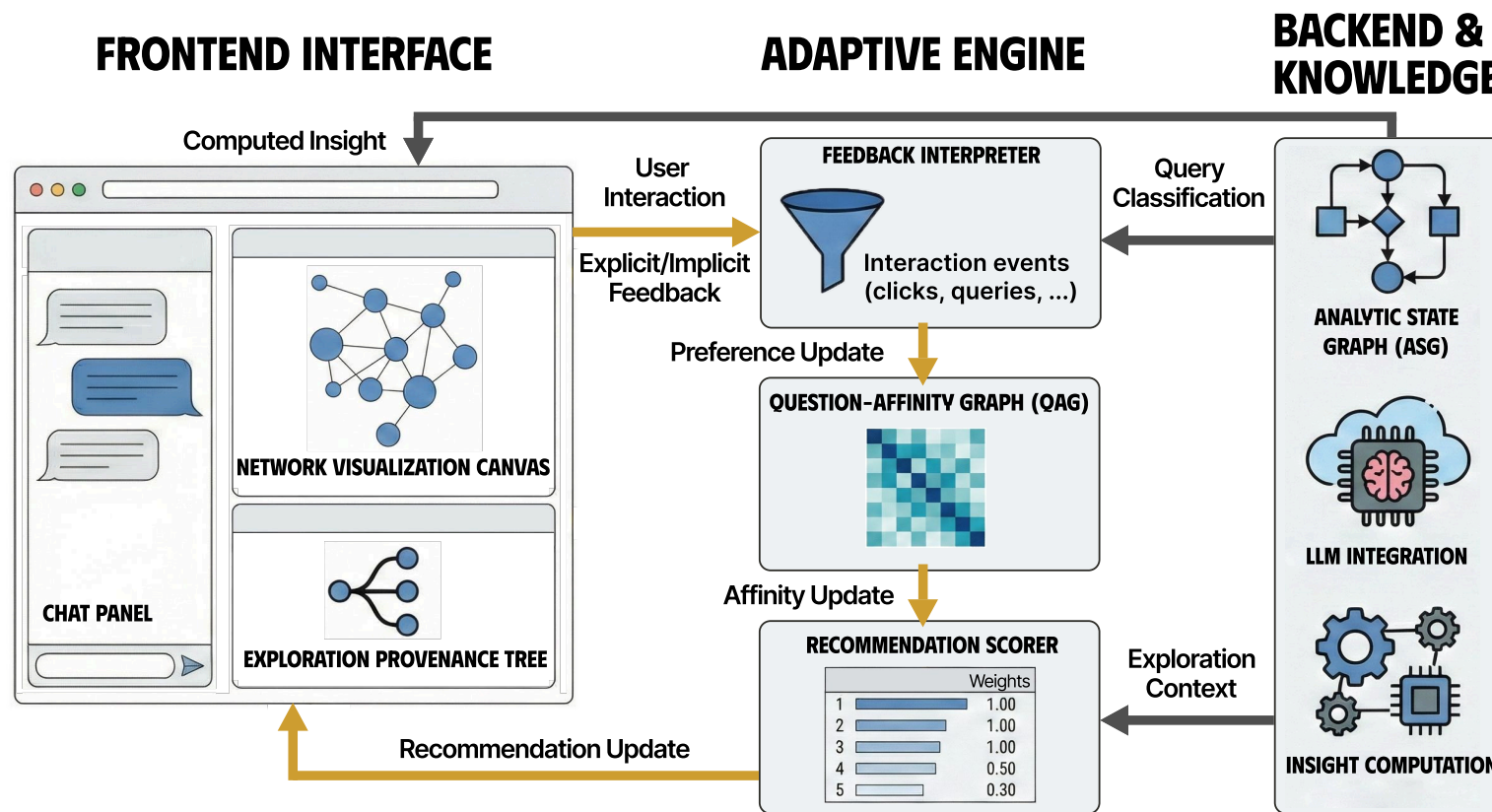
THE CLOSED LOOP

Interaction → Feedback signals → Preference update → Recommendation → Next interaction

Core System Modules

THE CLOSED LOOP

Interaction → *Feedback signals* → *Preference update* → *Recommendation* → *Next interaction*



INTERFACE WALKTHROUGH

The screenshot displays the NetworkCanvas interface, which is divided into several functional panels:

- Configuration Panel (A):** Located on the top left, it allows users to select a dataset (currently 'Company Ego Network') and adjust various visual parameters such as Node Size, Link Width, Layout (e.g., 'D3 Force Layout'), Node Color, Link Color, Label, and Arrow visibility.
- Chat Panel (B):** Situated below the configuration panel, it features a text input area and a 'Send' button. It displays natural language queries and their corresponding LLM-generated summaries, such as 'The ego's network splits into nine distinct social groups with clear boundaries.'
- Main Canvas (C):** The central workspace showing a network graph. It includes interactive tools for 'Single', 'Multi', and 'Lasso' selection, as well as a 'Clear' button. A right-click context menu is visible, offering options like 'Measure connectivity between two groups', 'Community & Detection', 'Network Overview', and 'Node Analysis'. A '3 Recommendations' button is located at the bottom of the canvas area.
- Explanation Panel (D):** A bar chart titled 'Community Sizes' is positioned at the bottom right of the main canvas, showing the distribution of nodes across different communities.
- Exploration Path (E):** On the right side, this panel provides a provenance tree of the user's exploration. It shows a sequence of nodes representing different views and analyses, such as 'Network Overview', 'Node Analysis', and 'Community Detection', with a 'Generate Exploration Report' button at the bottom.

- A Configuration**
Visual encoding controls: size, color, layout.
- B Chat Panel**
Natural language queries with adaptive recommendations at the bottom.
- C Main Canvas**
Interactive node-link view. Single, multi, and lasso selection. Right-click for contextual menus.
- D Explanation Panel**
Computed results and LLM summaries with factual and interpretive layers.
- E Exploration Provenance Tree**
Exploration history. Click any node to revisit. Fork new branches from any point.

Scenario Demo for a Traffic Engineer

The screenshot displays the NetworkCanvas application interface. On the left is the Configuration panel, which includes a 'Select example dataset' button, a dropdown for 'Selected dataset: Company Ego Network', and sliders for 'Node Size' (set to 8) and 'Link Width' (set to 0.8). It also features a 'Layout' dropdown set to 'D3 Force Layout', 'Node Color' and 'Link Color' dropdowns (both set to 'Cust.'), and 'Label' and 'Arrow' settings. Below this is a 'Chat' section with a question input field and a 'Generate Exploration Report' button at the bottom. The central Canvas area shows a dense network graph with blue nodes and gray links. A 'Question Recommendation' panel is overlaid on the graph, listing 'Network Overview', 'Node Analysis', and 'Community & Detection'. The right side of the interface features an 'Exploration Path' section with a legend for 'Question Categories' and a small tree diagram showing the current path.

- 1 Cold Start
- 2 Adaptation Kicks In
- 3 What-if analysis
- 4 Branching

Question-Affinity Graph(QAG): Learning Preferences from Implicit Feedback

A Question Categories

Table 5: Question Categories with Associated Entities and Insight Types

Question Category	Entity	Related Insight Type	Insight Description
1. Network Overview Questions about summarizing and measuring global structural properties and metrics of the entire network.	Network	Global Summary	Provide a concise synopsis of the entire network's topology and key metrics (size, density, connectivity).
6. Motif & Local Pattern Discovery Questions about detecting, counting, comparing, and evaluating statistically significant subgraph patterns or motifs.	Network/Group	Motif Detection	Locate occurrences of canonical subgraphs (e.g., triangles, feedforward loops).
		Motif Counting	Compute the frequency of each motif type within the network.
		Statistical Significance	Assess motif overrepresentation against randomized graph ensembles.
		Motif Enumeration	List explicit node sets forming each instance of a given motif.
		Pattern Comparison	Contrast motif distributions across subgraphs.
7. Attribute-based Exploration Questions about filtering, identifying extremes, visualizing distributions, and analyzing statistical summaries based on entity attributes.	Network/Group/ Node/Link	Attribute Filtering	Select entities meeting attribute predicates (e.g., weight > X).
		Identify Extremes	Find nodes or links with maximum or minimum attribute values.
		Distribution Analysis	Visualize attribute histograms or heatmaps to assess value dispersion.
		Aggregate Statistics	Calculate mean, median, variance, or quartiles for selected attributes.
		Comparative Filtering	Compare attribute distributions between subsets (e.g., groups).
8. Attribute-Topology Correlation Questions about assessing relationships and correlations between network topology and entity attributes.	Network/Group	Correlation Computation	Measure statistical correlation between structural metrics and attributes (e.g., degree vs. tenure).
		Assortativity Analysis	Quantify homophily by assessing attribute similarity along edges.
		Topology-Conditioned Aggregation	Summarize attribute statistics within structural subsets (e.g., communities).
		Conditional Filtering	Filter entities by combined attribute and topology criteria (e.g., high-degree nodes with attribute X).
9. Outlier & Anomaly Detection Questions about detecting, identifying, and ranking unusual or anomalous nodes, links, groups, or subnetworks.	Network/Group/ Node/Link	Node Outlier Identification	Detect nodes with attribute or metric values that deviate significantly from the norm.
		Link Anomaly Detection	Flag links exhibiting unexpected weights or interaction patterns.
		Subgraph Anomalies	Identify groups or subnetworks with anomalous density or motif counts.
		Anomaly Ranking	Score and rank entities by their anomaly magnitude to prioritize investigation.
10. What-If Analysis Questions about simulating hypothetical changes to network elements or parameters and evaluating resulting structural impacts.	Network/Group/ Node/Link	Element Removal Simulation	Delete nodes or links hypothetically and recompute metrics to assess impact.
		Element Addition Scenario	Add hypothetical links or nodes and evaluate resulting structural changes.
		Parameter Sensitivity	Vary weights or attribute parameters to observe metric fluctuations.
		Optimization Queries	Identify minimal edits needed to achieve a topological goal (e.g., restore connectivity).

Question Categories



A 10×10 affinity matrix over analytical question categories.

Context-Aware Feedback & Recommendation Scoring

QAG ASYMMETRIC UPDATE RULES

ACCEPT diminishing returns

$$w_{A \rightarrow B}^{t+1} = w_{A \rightarrow B}^t + \eta \cdot (1 - w_{A \rightarrow B}^t)$$

$\eta = 0.05$. At $w = 0.9$, only 10% of the learning rate contributes.
Weights never saturate, so diversity is preserved.

SKIP soft penalty

$$w_{A \rightarrow C}^{t+1} = w_{A \rightarrow C}^t - \lambda \cdot \eta \cdot w_{A \rightarrow C}^t$$

$\lambda = 0.3$. Skips are ambiguous in exploration. Gentler penalties prevent premature dismissal.

MULTI-CRITERIA SCORING

$$\text{Score}(r) = \alpha \cdot \text{Affinity}(r) + \beta \cdot \text{DOI}(r) + \gamma \cdot \text{Synergy}(r) + \delta \cdot \text{Relevance}(r)$$

Affinity dominates, but stays below 0.5. Context and feasibility still shape the final ranking.

Evaluation: Two Controlled Studies

STUDY 1

Comparative Exploration

Design: within-subject, 14 participants

Task: open exploration of data lineage networks

Datasets: simple (464 nodes) and medium (2,024 nodes)

Duration: 15 minutes per condition, counterbalanced

STUDY 2

Task-Based Evaluation

Design: between-subject, 16 participants (n = 8 each)

Task: goal-directed transportation analysis

Dataset: Road network (416 intersections)

Participants: no prior network-analysis expertise

BASELINE same visualization, no recommendations

This isolates the recommendation paradigm versus unguided exploration. It does not isolate adaptive personalization versus any structured guidance. We revisit this on the limitations slide.

Key Results

+46%

more noteworthy observations

12.3 vs 8.4 · $d = 1.35$

87.5%

Task 1 success rate

vs 50% baseline · $p = .039$

73%

recommendation acceptance

across all sessions

QUALITATIVE THEMES

Guided discovery **12 / 14**

Reduced analysis paralysis **9 / 14**

Enhanced pattern recognition **8 / 14**

Concerns about over-reliance **5 / 14**

“It's like having an expert guide pointing out what's interesting.”

Guided discovery · P7

“With the baseline, the first few minutes were just wandering.”

Reduced paralysis · P9

“I worry I'm being led down a path and missing other discoveries.”

And the concern we take seriously. · P5

Limitations: What Our Study Cannot Claim

- **Evaluation baseline:** Our baseline had no recommendations at all. We cannot isolate whether benefits come from adaptive personalization or from any form of structured guidance.
- **Scalability Ceiling:** Responsive interaction up to $\sim 10\text{K}$ nodes. Larger networks require engineering extensions.
- **Empirical Tuning:** Learning rates (η, λ) set through pilot testing. No theoretical guarantees.

Contributions and Future Work

CONTRIBUTIONS

01

QAG & Recommendation framework

Heuristic workflow-affinity model with asymmetric updates and multi-criteria scoring.

02

NetworkCanvas system

Adaptive guidance integrated with provenance-aware branching.

03

Empirical evidence

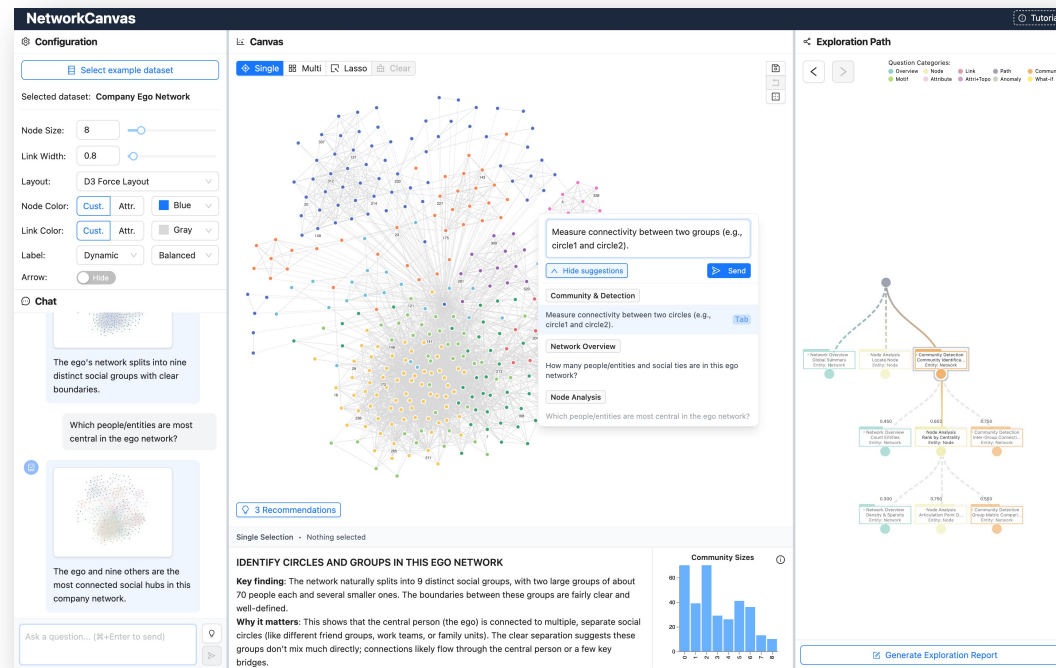
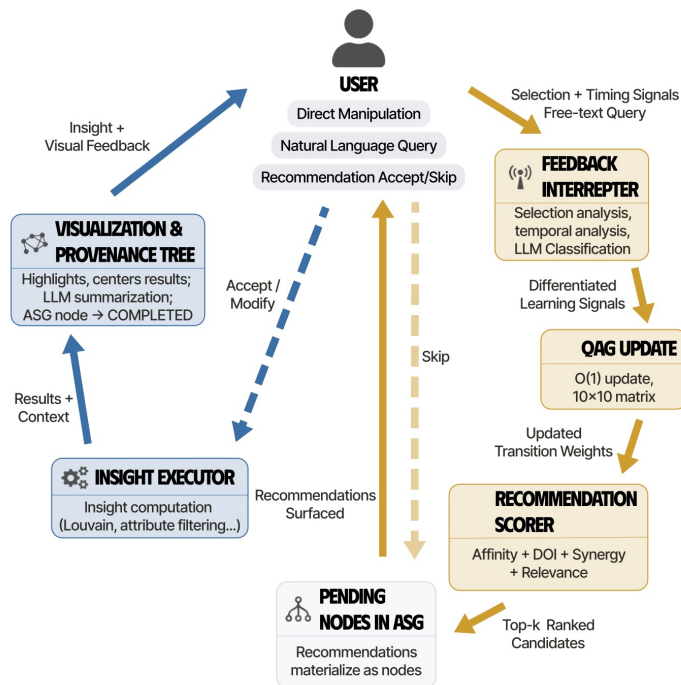
Two controlled studies show improved observation discovery and user confidence.

FUTURE WORK

- Ablation studies: adaptive vs static vs randomized recommendations
- Temporal networks leveraging the ASG structure
- Cross-domain validation
- Collaborative multi-analyst exploration with shared provenance

NetworkCanvas:

Supporting Progressive Network Visualization Exploration via Adaptive Recommendations



✉ wenc.li@outlook.com

🏠 <https://wenchao.li>