Efficient Generation of Geographically Accurate Transit Maps

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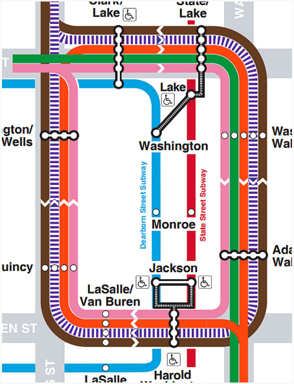
Motivation

Official CTA map



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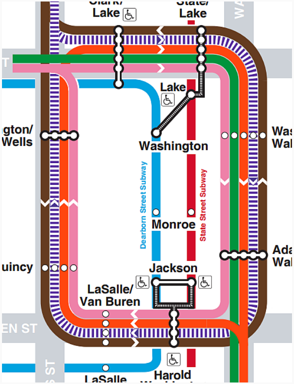
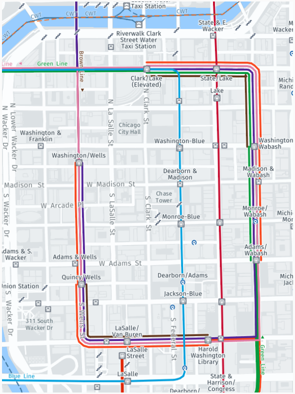


HERE



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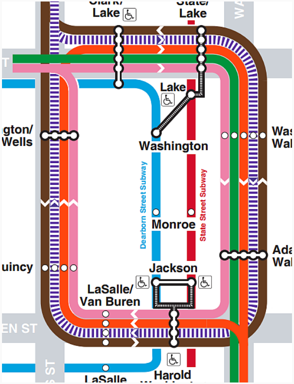

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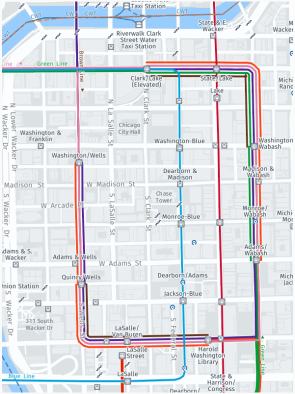
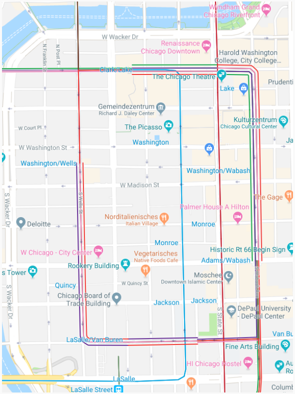


Google



Goal

Goal: Generate these maps automatically, in high quality

”Bag of trips”

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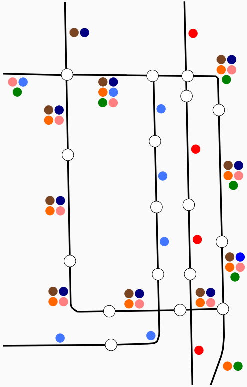

”Bag of trips”

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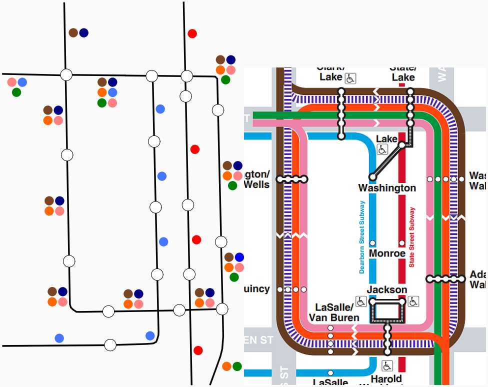
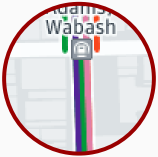


"Bag of trips"

Challenges

Official

HERE



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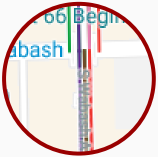
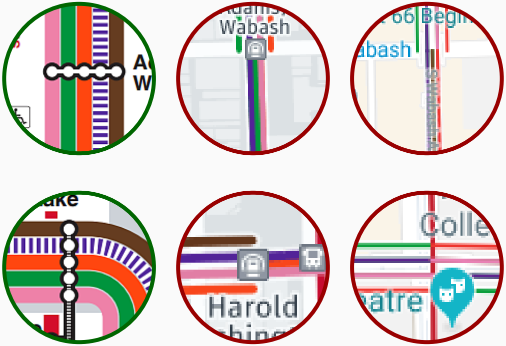


I. Avoid line overlaps

Challenges

Official HERE Google

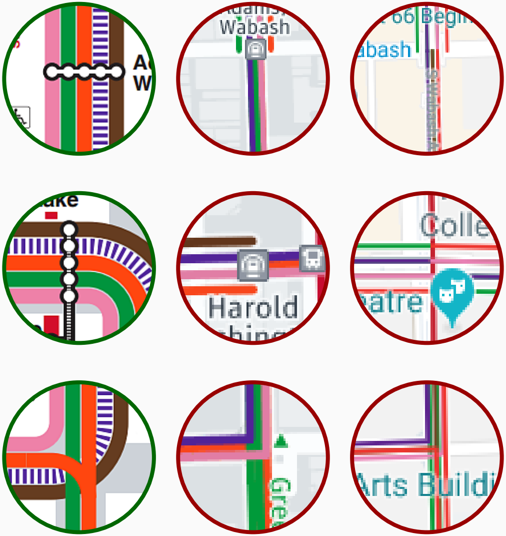


I. Avoid line overlaps

II. Match line orderings

Challenges

Official HERE Google



I. Avoid line overlaps

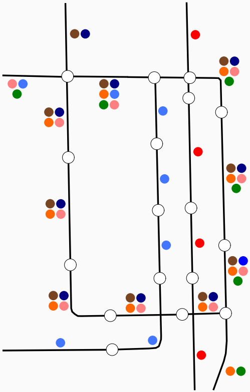
II. Match line orderings

III. Clearly indicate line continuations

Line graph construction

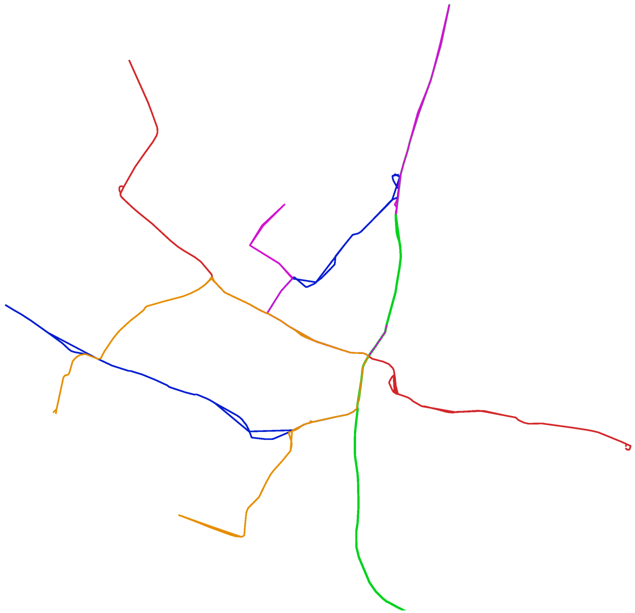
Line graph:

- Undirected labeled graph $G = (V, E, L)$
- Edge labels are subsets of the network lines $\mathcal{L}$ ($L(e) \subseteq \mathcal{L}$)
- Nodes are usually stations

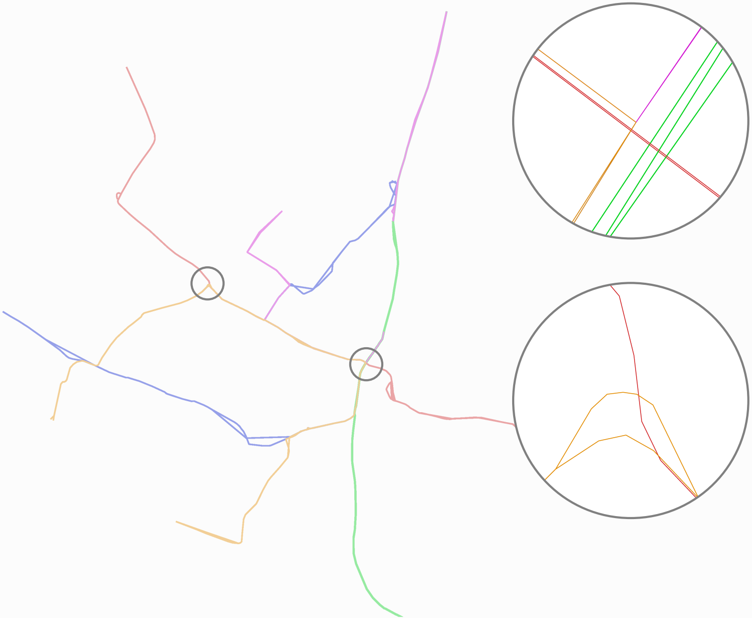


Example: $\mathcal{L} = \{\}$ and $L((a,b)) = \{\}$

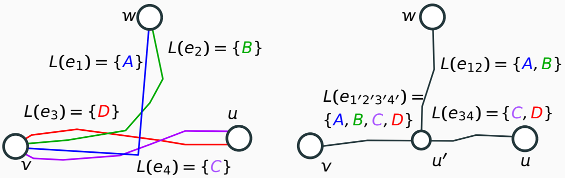
Line graph construction - Input data



Line graph construction - Input data

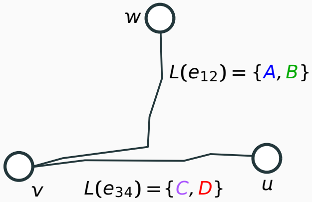


Line graph construction - Shared segment collapsing

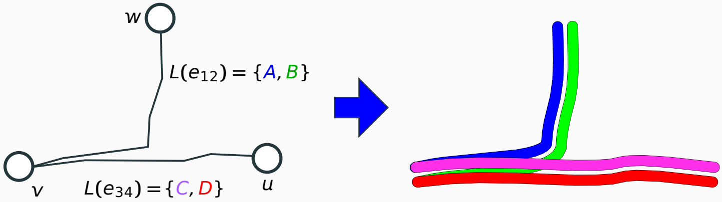


- Repeatedly collapse (segments of) two edges e and f within a distance $\hat{d}$
- Sweep over some edge e in steps of 10 m, measure distance d of current point on e to f
- If $d < \hat{d}$, start new segment. If not, end current (if open)
- Take average between the two ”shared segments” on e and f
- Add additional non-station nodes at segment boundaries

Line graph construction - Why non-station nodes?



Line graph construction - Why non-station nodes?



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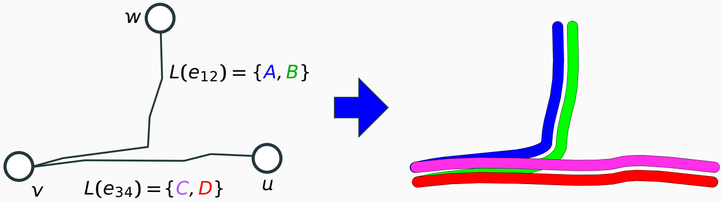

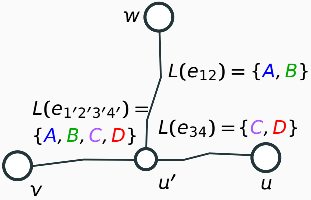

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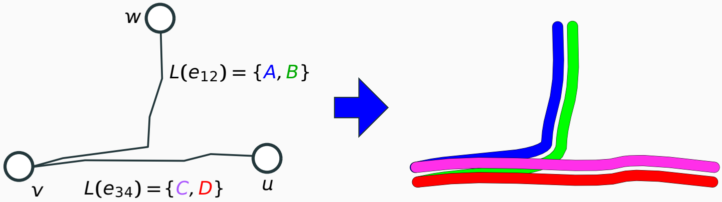
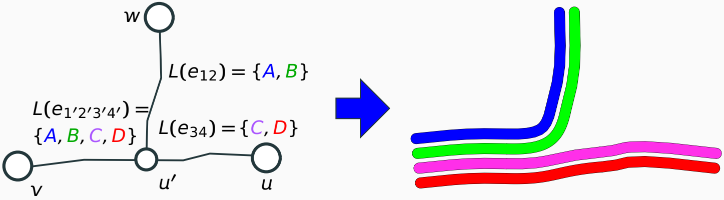
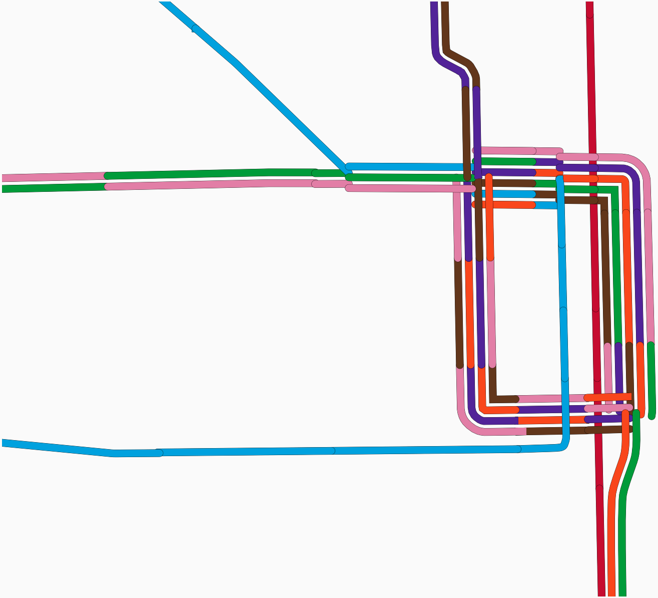




Results so far (1)



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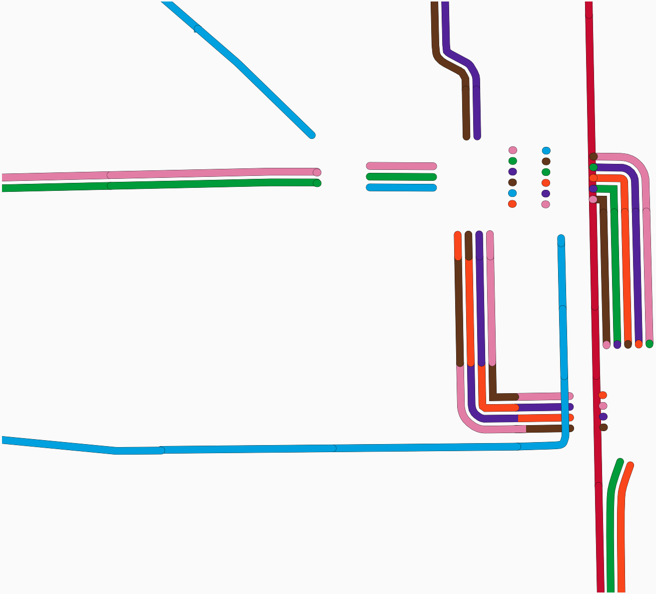
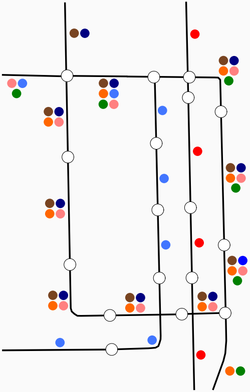


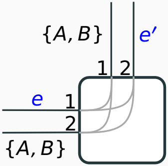
Line-ordering optimization

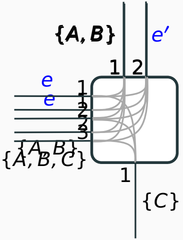


- 23 edges
- Each edge e has $|L(e)|!$ possible line permutations
- Possible configurations for the graph on the left: $> 2 \times 10^{17}$

$\Rightarrow$ **Naive exhaustive search infeasible**

Line-ordering optimization - Baseline ILP





- For each edge e, line l and position p, introduce variable $x_{elp} \in 0, 1$
- Example: x_{eA1} and x_{eA2} for line A
- Constraint: all x_{elp} have to sum up to 1 for a single line l on a single edge e
- Standard crossing: Objective variable $x_{ee'AB}$ which is 1 if $p_e(A) < p_e(B)$ and $p_{e'}(A) > p_{e'}(B)$, or else 0
- Split crossing: Objective variable $x_{ee'e''AB}$ which is 1 if $p_e(A) < p_e(B)$, or else 0

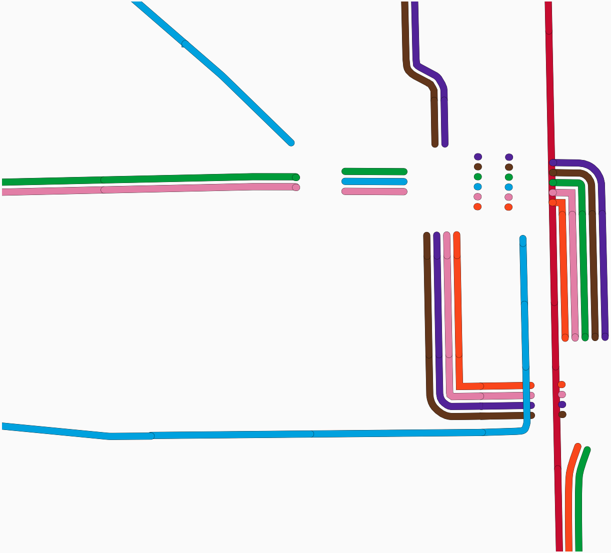
$\Rightarrow \mathcal{O}(|E|M^2)$ variables, $\mathcal{O}(|E|M^6)$ constraints

Line-ordering optimization - Improved ILP

- **Observation:** we only need to check if $p_e(A) < p_e(B)$ (or vice versa) for both types of crossings
- But we explicitly enumerate all possible line positions of A and B on e
- Basic idea: introduce binary variables $x_{eA<B}$ and $x_{eB<A}$ which can be efficiently checked

$\Rightarrow \mathcal{O}(|E|M^2)$ variables, $\mathcal{O}(|E|M^2)$ constraints

Results so far (2)



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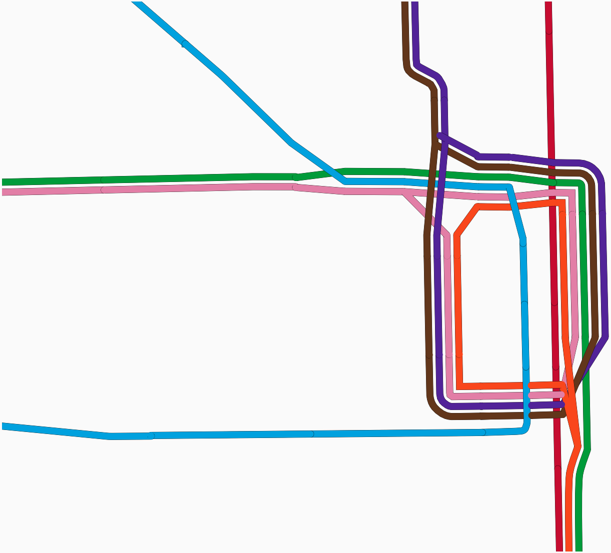

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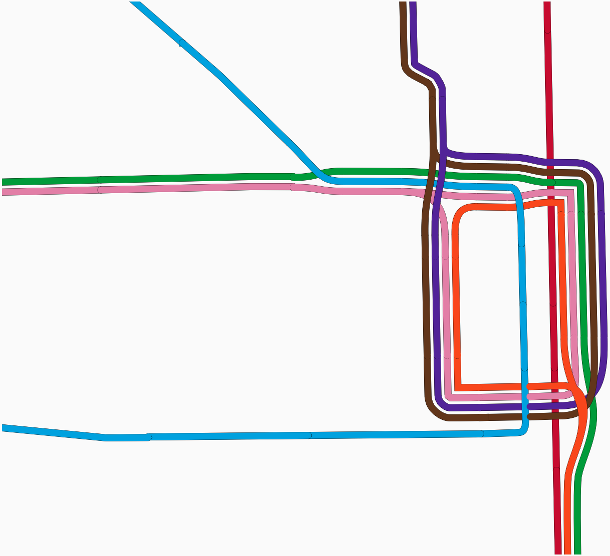
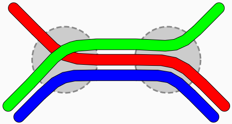


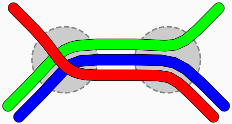
Line-ordering optimization - Line separations

vs

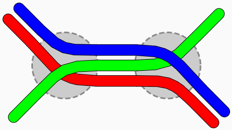
vs



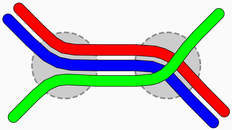
1 crossing, 1 separation



2 crossings, 0 separations

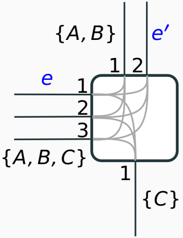


2 crossings, 1 separation



2 crossings, 0 separations

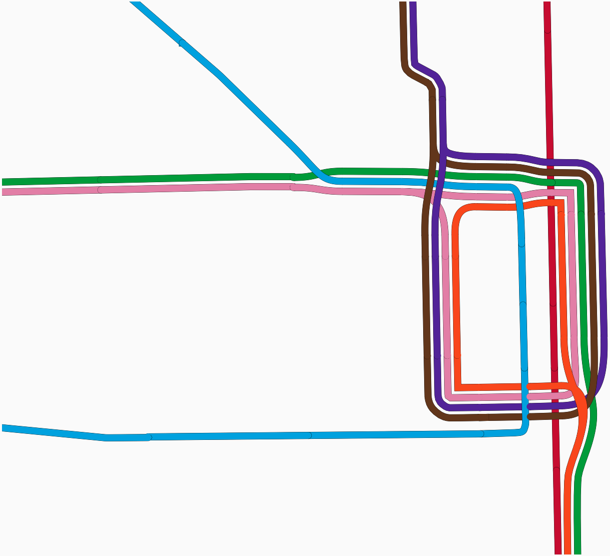
Line-ordering optimization - Line separations (ctd.)



- **Idea:** If two lines A, B continue from e to e', set a binary splitting variable $x_{ee'A\|B} = 1$ if they are next to each other in e, but no in e'
- Add $x_{ee'A\|B}$ to the objective function

$\Rightarrow$ Still $\mathcal{O}(|E|M^2)$ variables, $\mathcal{O}(|E|M^2)$ constraints

Results so far (3)



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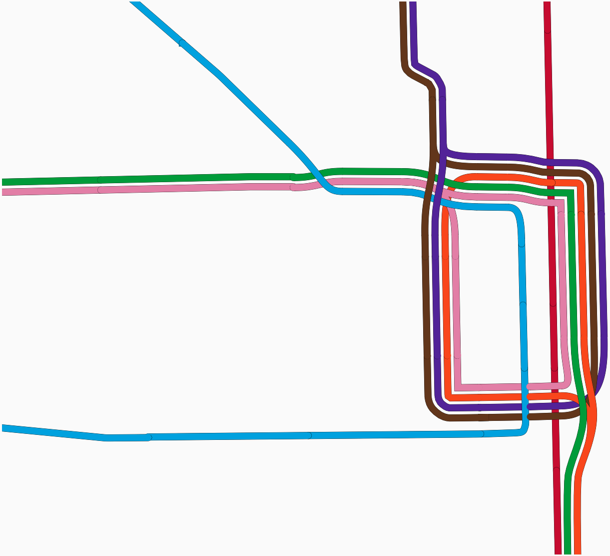
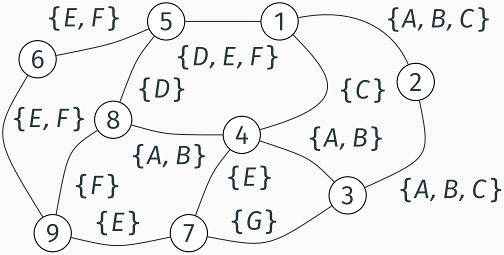


Line-ordering optimization - Core optim graph



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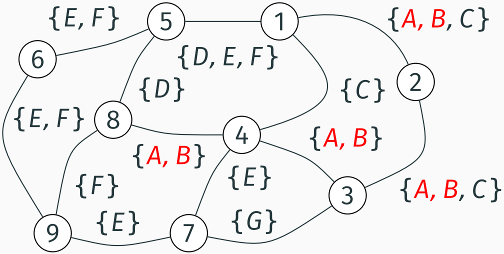

- Combine lines *A*, *B* that always occur together into a single new line ($A, B \longrightarrow X$)

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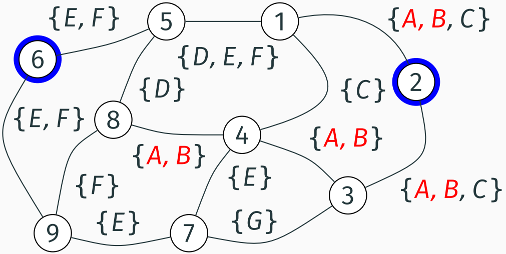

- Combine lines A, B that always occur together into a single new line ($A, B \longrightarrow X$)
- Delete nodes with degree 2 and merge their adjacent edges

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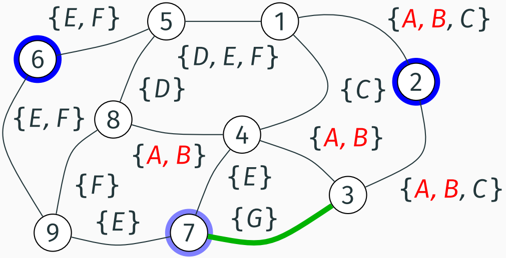

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- Remove edges (u, v) where u and v are termini for all $L((u, v))$

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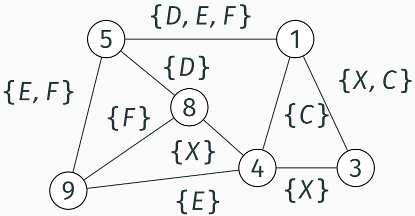

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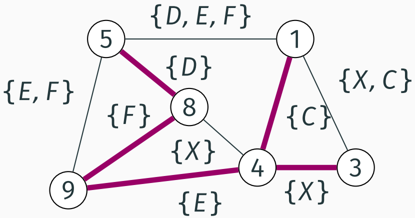

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- Cut edges with $|L(e)| = 1$

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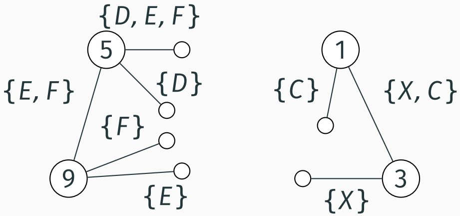

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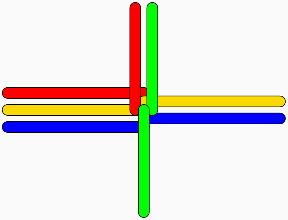
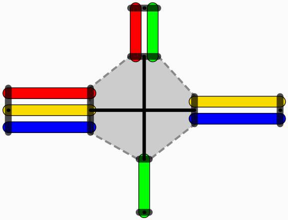
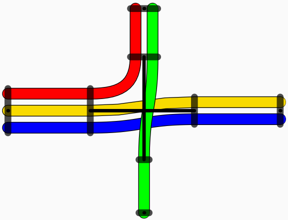
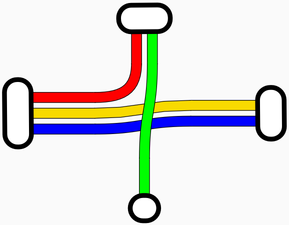
Rendering









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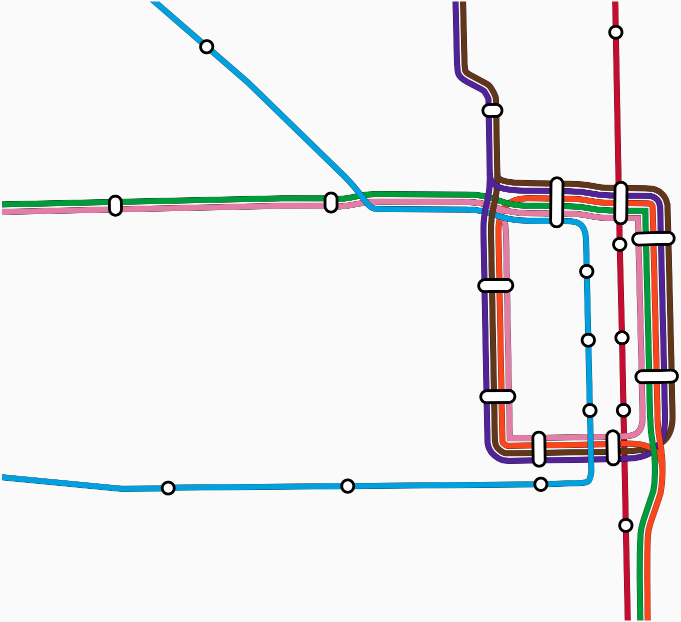

Evaluation

Future work

- Additional rules for core graph reduction (work in progress)
- Faster construction times of line graph
- TODO

Thank you!