Computing optimal flow decompositions for assembly

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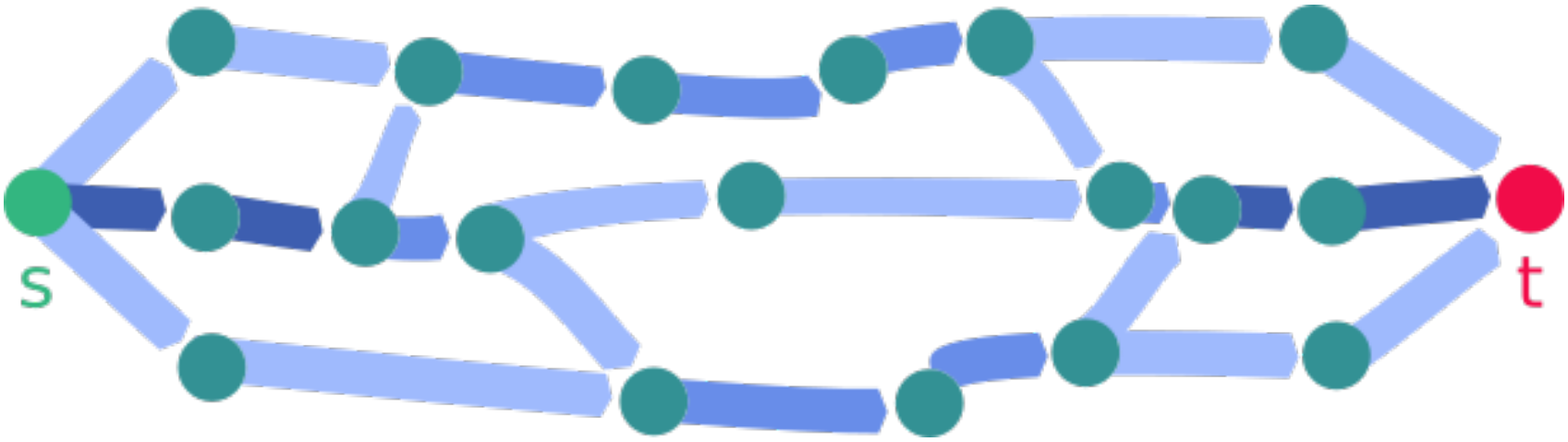
Motivation

The Problem

Shared segments between DNA/RNA strands create ambiguity in the assembly problem

The Problem



Connecting overlapping segments and counting their frequencies yields a splice-graph.

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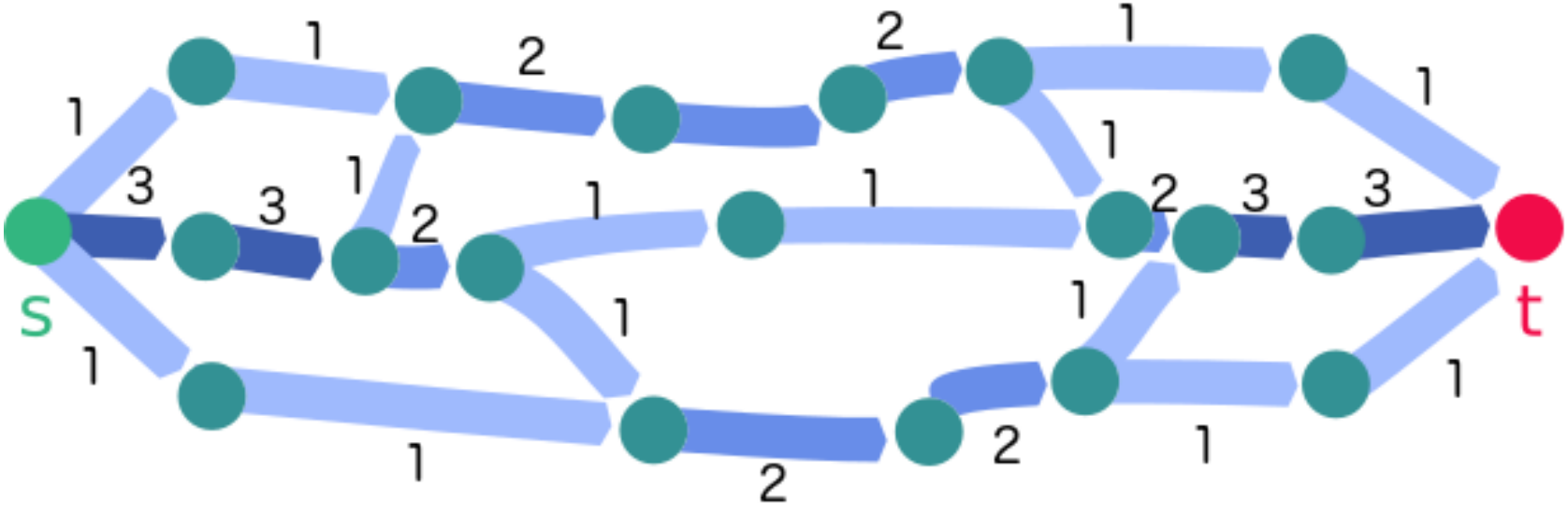

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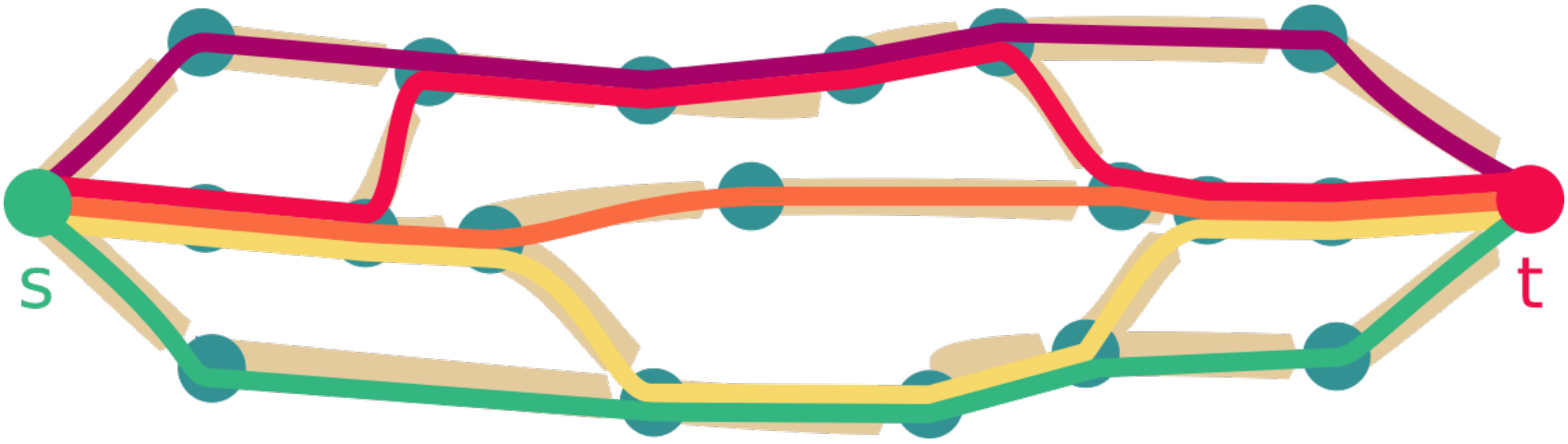

The problem is to split the flow into s-t-paths, to recover the original DNA/RNA strands.

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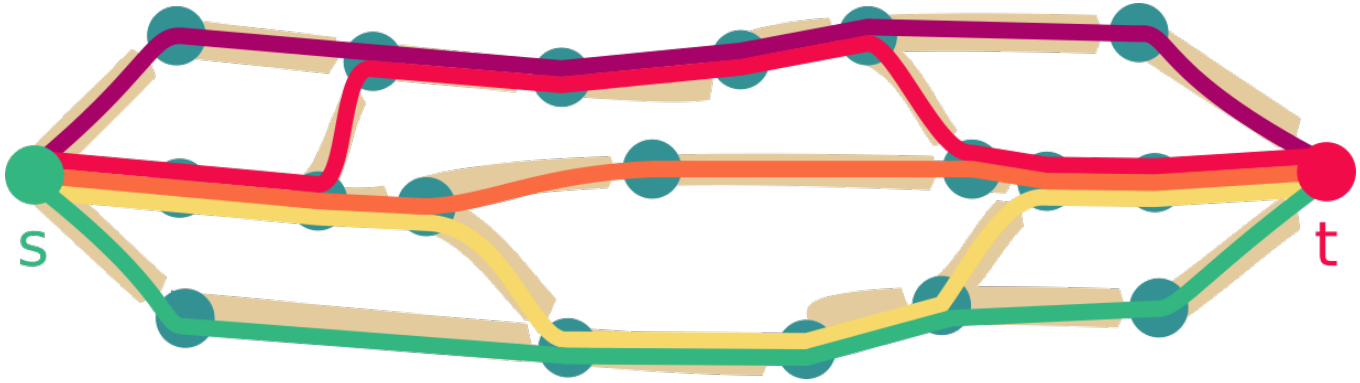

AGGACGTAGATAGCTAGCTAATGCTACGATCAGAGGACGTAGATTTATTACCAT

TACCGAATACGAACTAGGATATCGATCGATCAGAGGCCCAATAGGGAATATCCG

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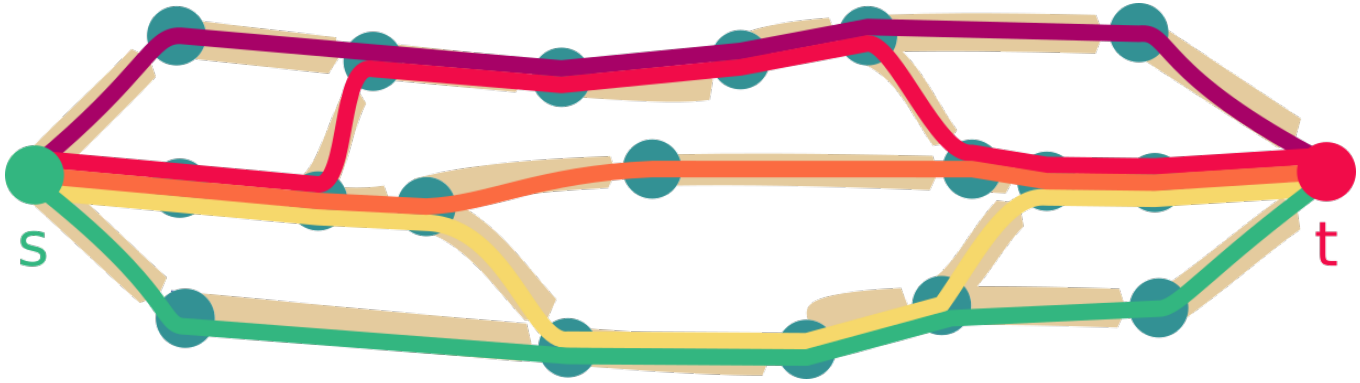

k-Flow Decomposition (*k*-FD)

Input: (G, f, k) with an s-t–DAG G, a flow f on G, and a positive integer k.

Problem: Find an integral *flow decomposition* of (G, f) using at most k paths.

Related Work

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Problem is NP-hard even for weights $\{1, 2, 4\}$

How to split a flow?
T. Hartman et. al.

Computer Scientists…

About ten years ago, some computer scientists came by and said they heard we have some really cool problems. They showed that the problems are NP-complete and went away!

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Linear FPT

$$c^n \quad \text{vs.} \quad d^k \cdot n$$

linear fpt: exponential only in the *parameter* and linear in n!

Observations

Data used by Shao and Kingsford:

1. 99% of instances decompose into ≤ 8 paths.
   $\rightarrow$ exploit **small natural parameter**.
2. ~4 million mostly small instances.
   $\rightarrow$ handle **large throughput**.
3. Output decompositions.
   $\rightarrow$ reliably recover **domain-specific solution**.

Toboggan

Theorem

Toboggan *solves* k-FD *in* $2^{O(k^2)}(n + \lambda)$*, where* λ *is the logarithm of the largest flow value.*

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- Run-time competitive with current state of the art heuristic
- Usable in practice

Implementation & Experiments

Repository

https://github.com/theoryinpractice/toboggan

Setup

Dataset: Available from Shao and Kingsford. Simulated sequencing data for `human`, `mouse` and `zebrafish`, containing ground-truth.

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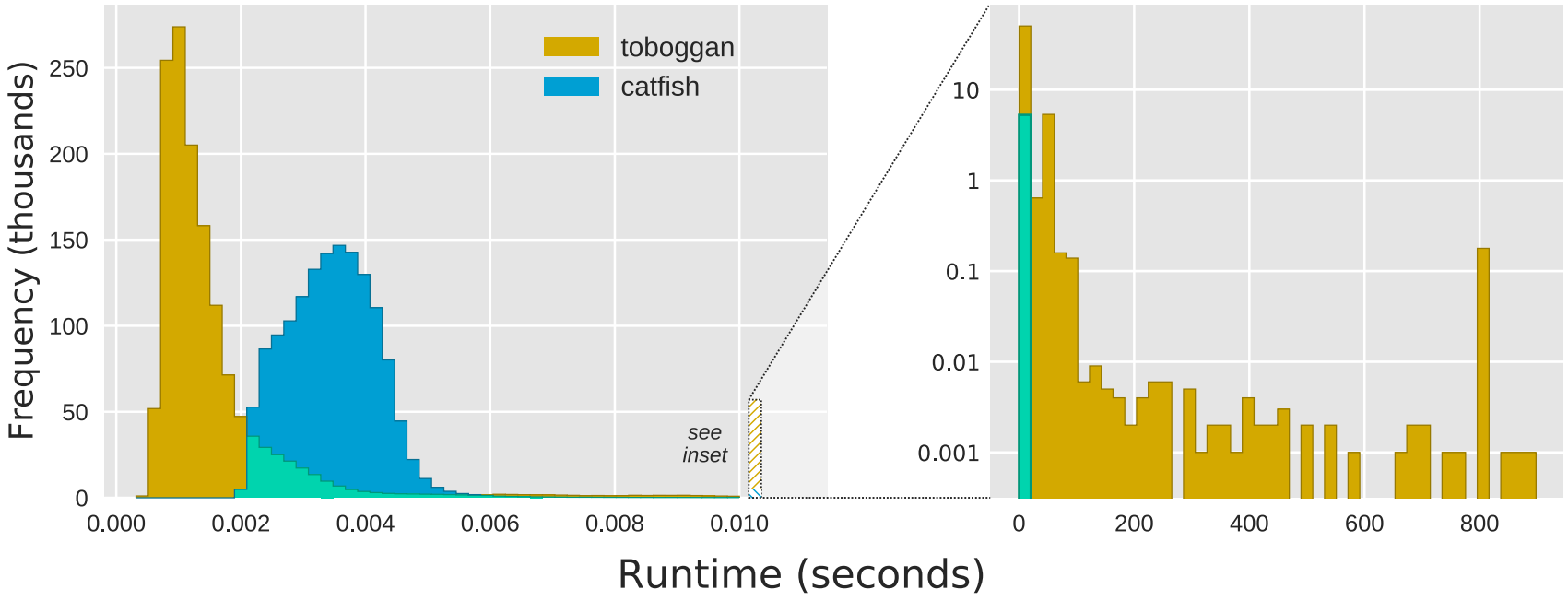
Dedicated system with Intel i7-3770:
3.40 GHz, 8 MB cache and 32 GB RAM.

Execution Time



Median:

Toboggan: 1.24ms

Catfish: 3.47ms

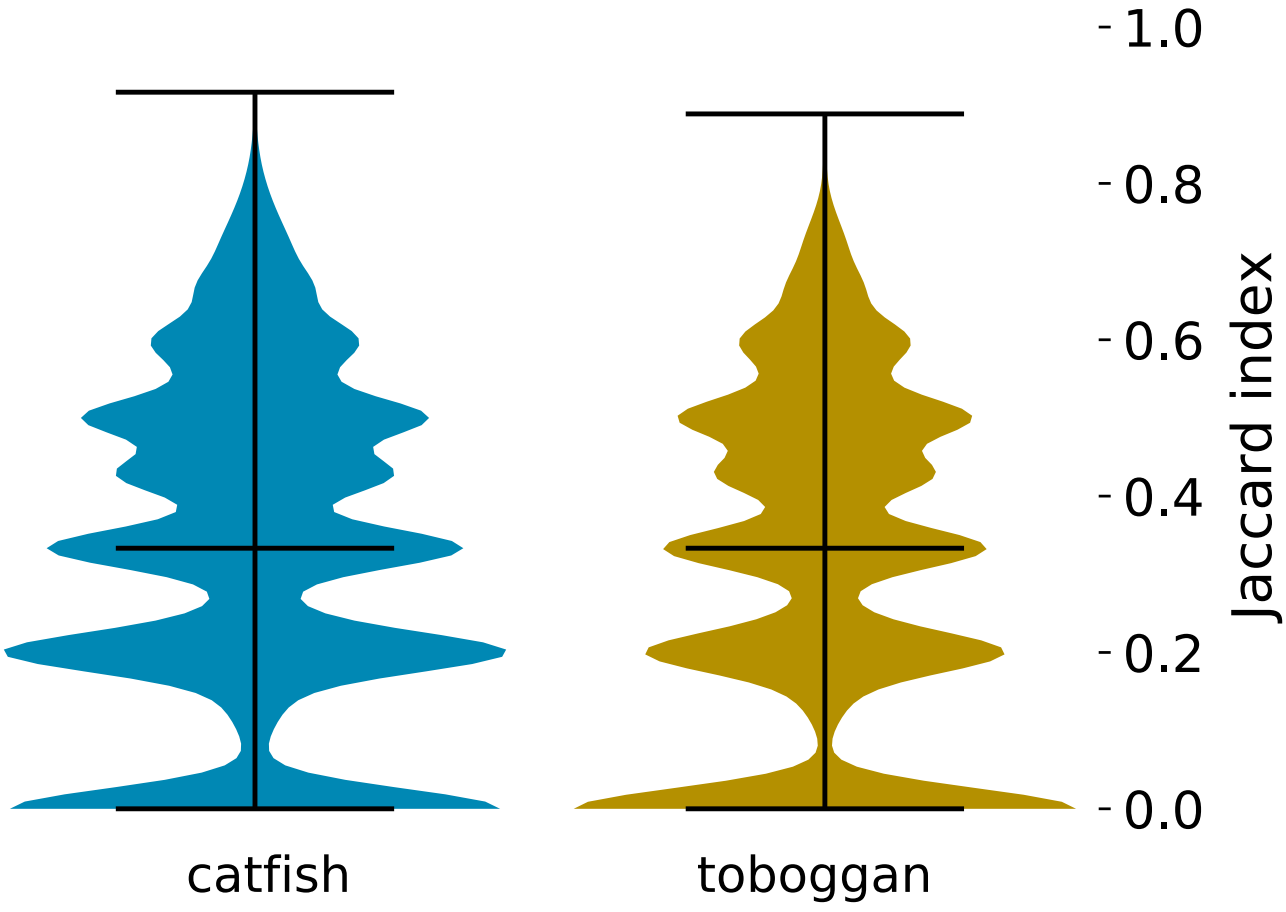
Ground Truth Validation

dataset	instances	minimal	non-minimal
`zebrafish`	445,880	99.907%	0.053%
`mouse`	473,185	99.401%	0.074%
`human`	529,523	99.490%	0.043%
all	1,448,588	99.589%	0.056%

Exact Recovery

k	instances	Catfish	Toboggan
2	63.2791%	0.992	**0.995**
3	22.0775%	0.967	**0.969**
4	8.5237%	**0.931**	0.930
5	3.4920%	0.886	0.886
6	1.5375%	**0.830**	0.828
7	0.6698%	**0.788**	0.780
8	0.2889%	**0.767**	0.766
9	0.1241%	0.740	**0.743**
10	0.0070%	0.752	**0.802**
11	0.0004%	0.500	0.500
all	100%	0.973	**0.975**

Solutions vs. Ground Truth



Algorithm Idea

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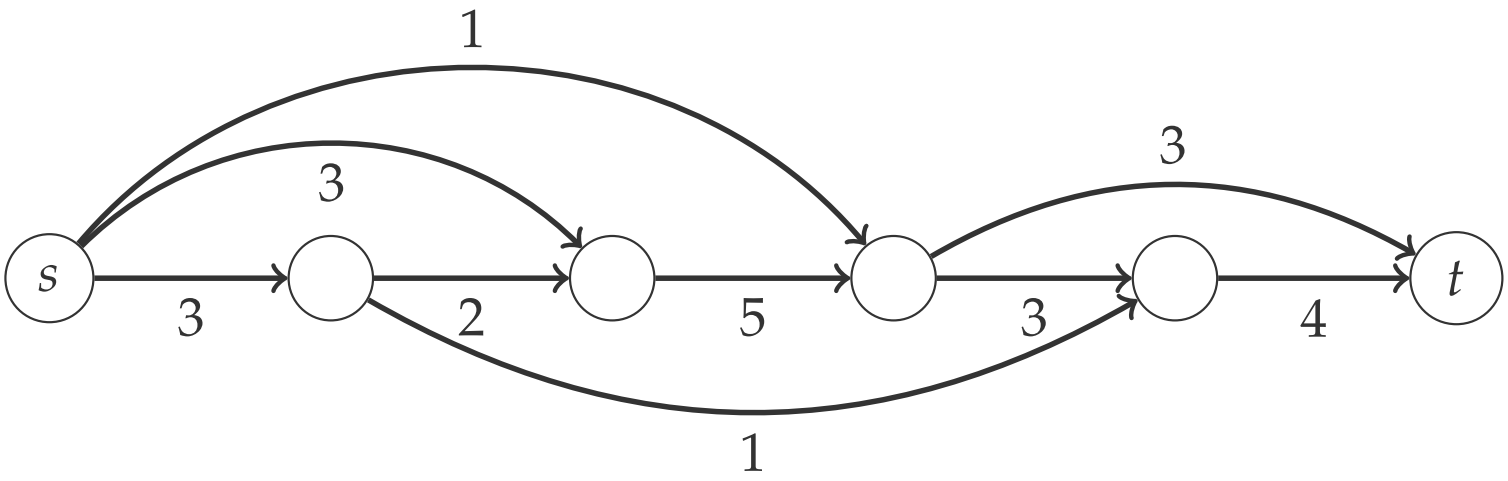

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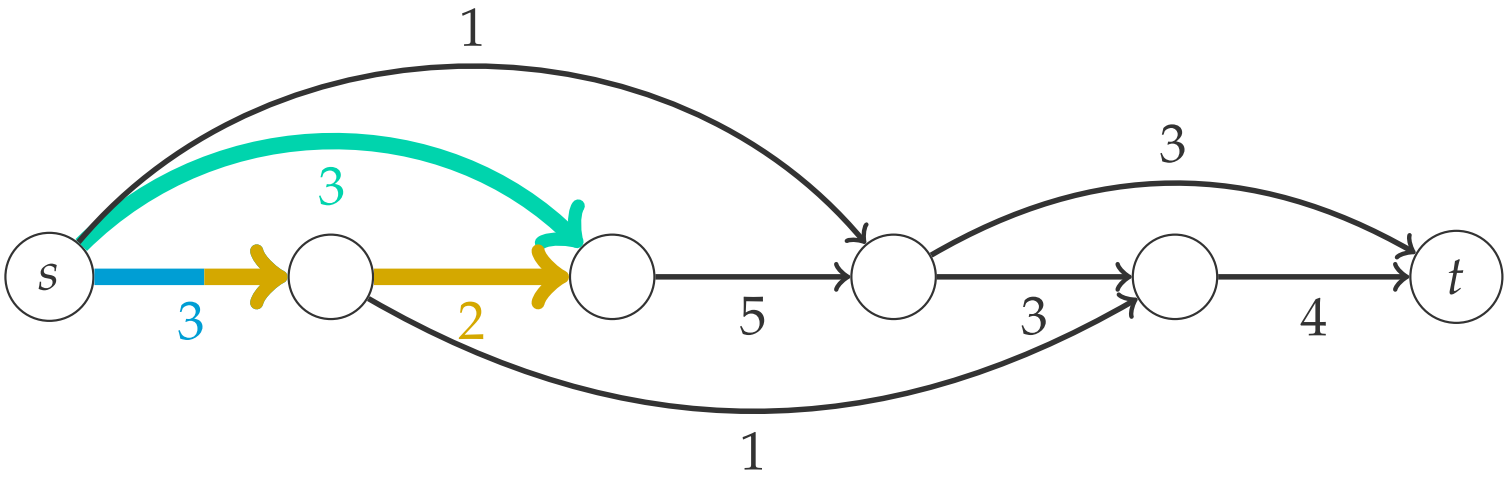

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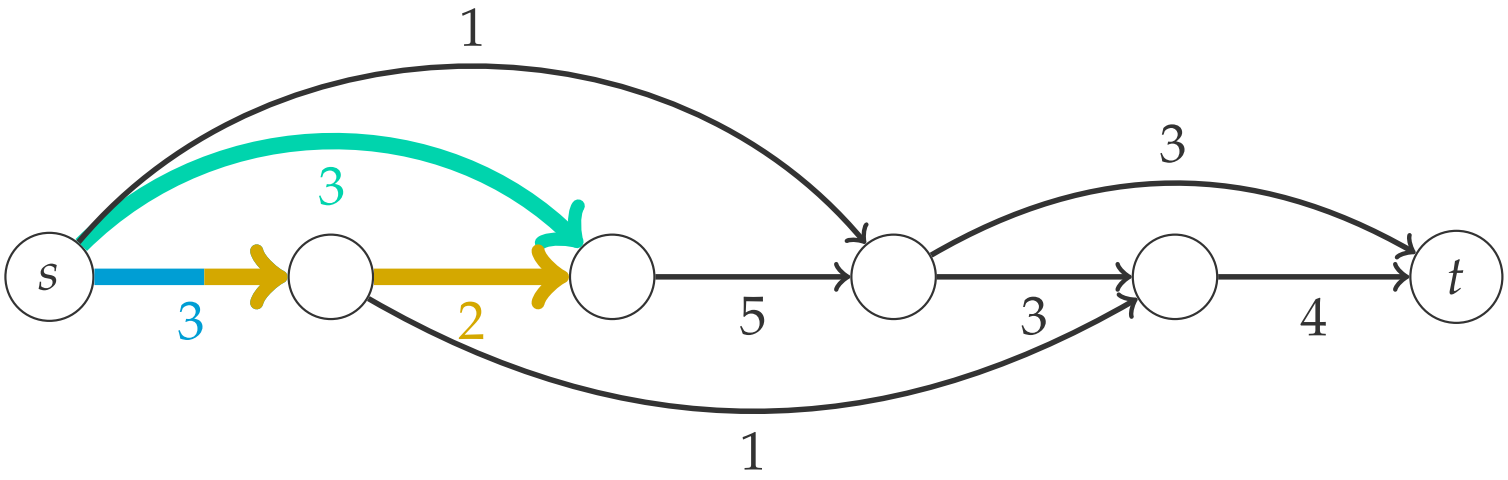

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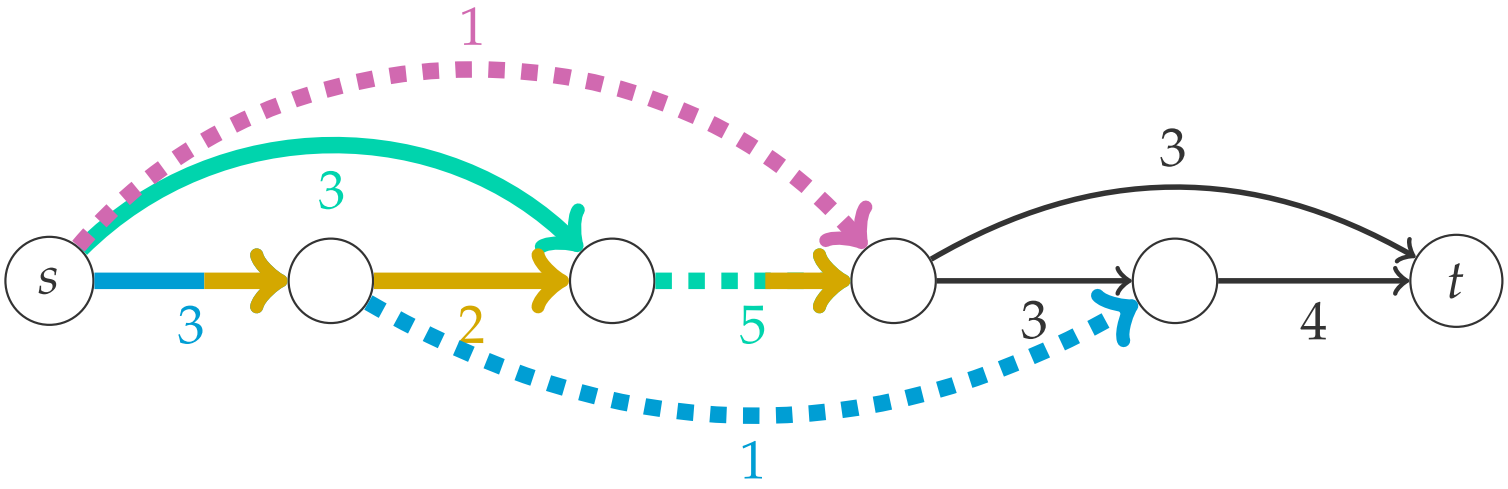

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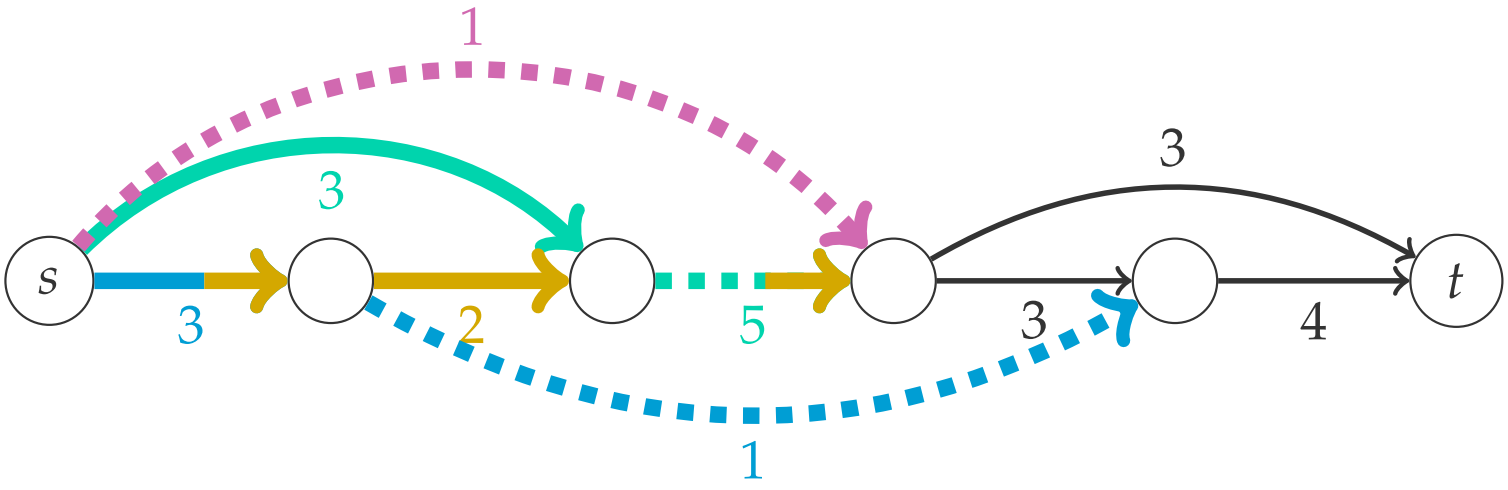

$$w_{\blacksquare} + w_{\blacksquare} = 3 \qquad w_{\blacksquare} = 1$$

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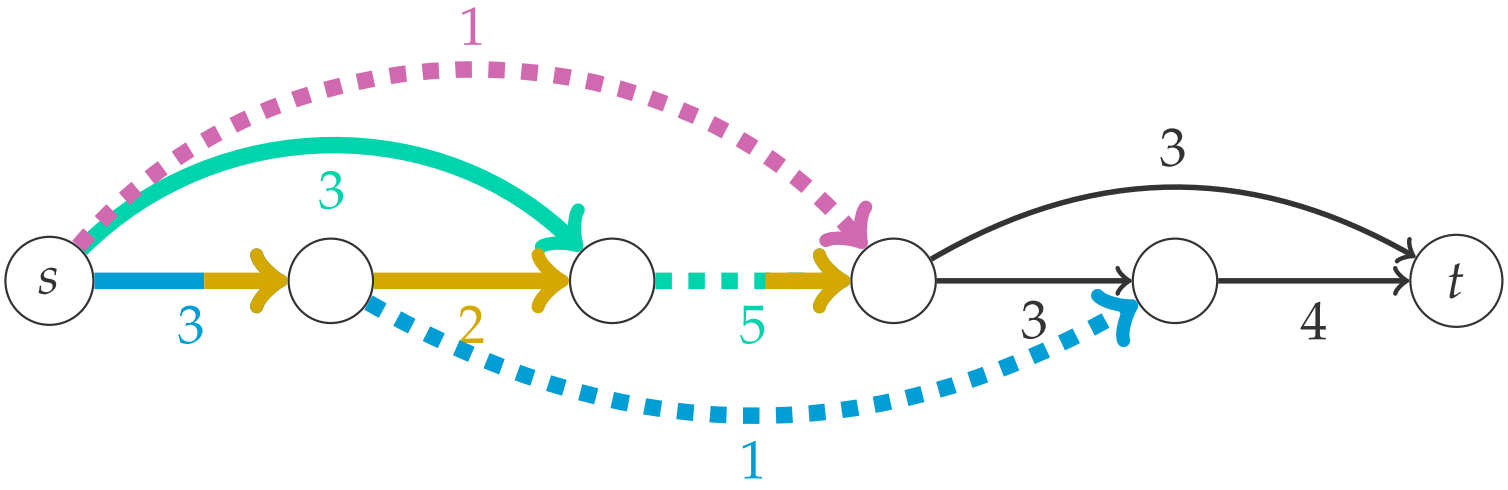

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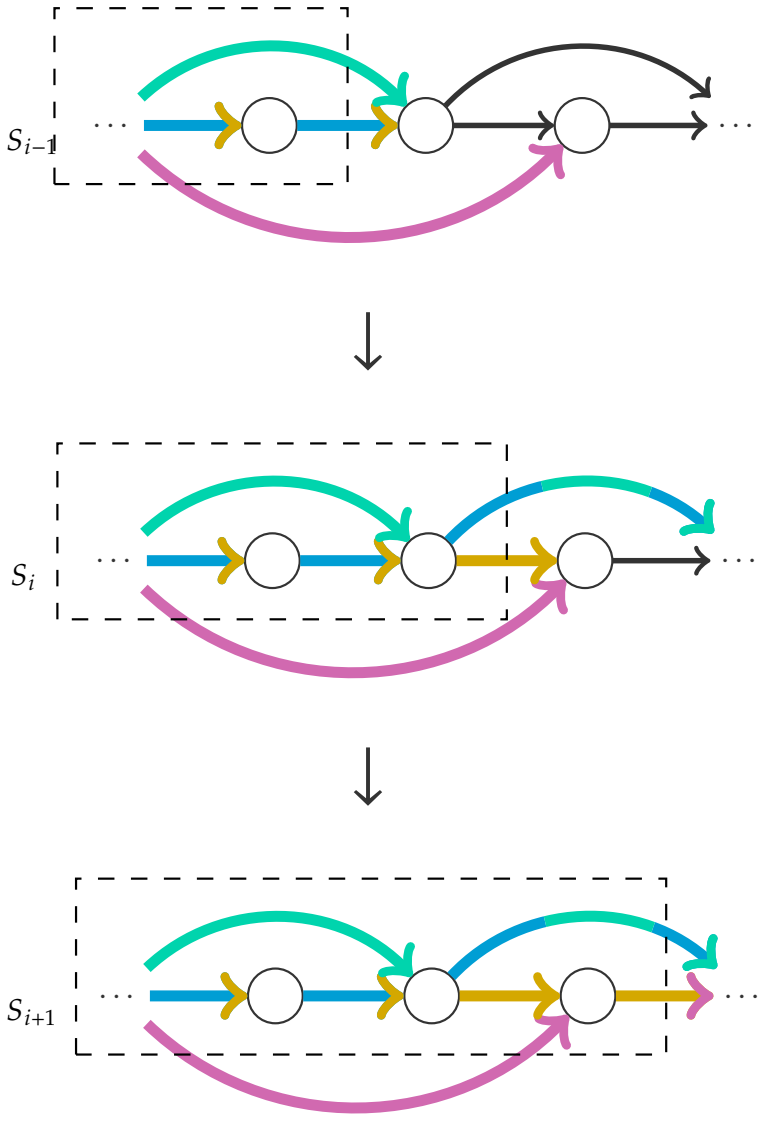
$$Aw = f$$

Dynamic Programming



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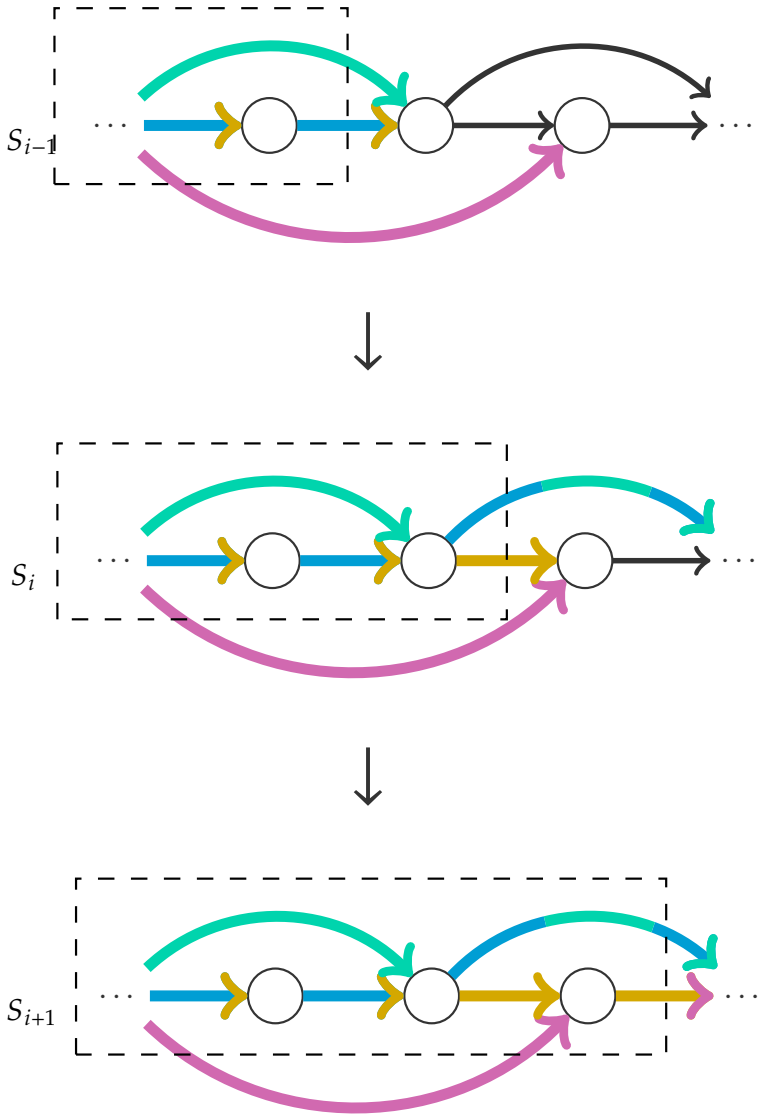

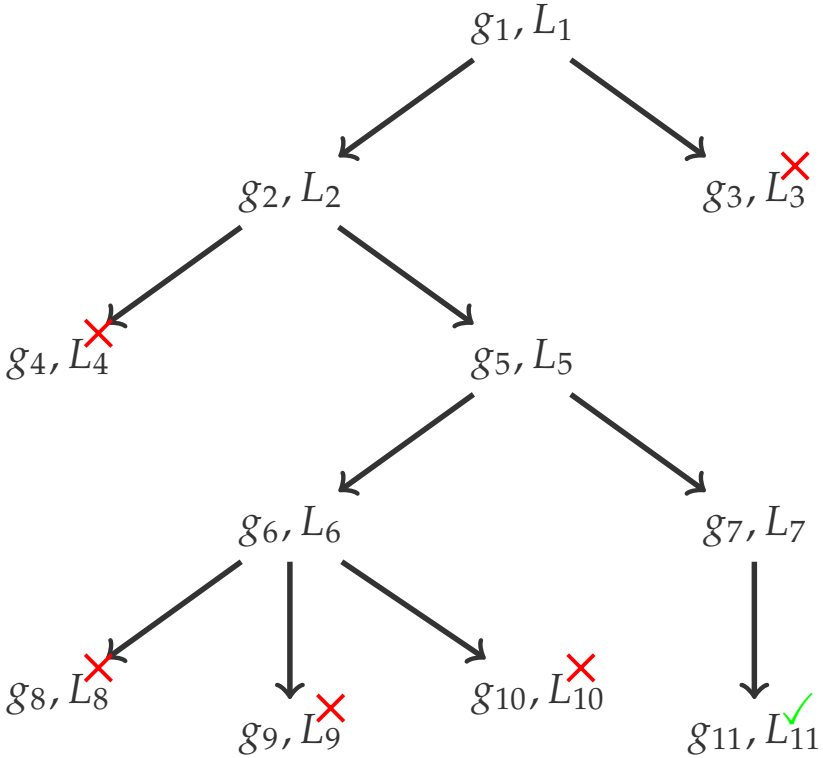

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Thank you!

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