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Counting to *k*, or how SPARQL1.1 Property Paths Can Be Extended to Top-k Path Queries

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Shortcomings of the existential sematnics of path expressions

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No way to get the nodes / properties / length of arbitrary paths in SPARQL 1.1

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Top k shortest path queries

- More informative than the existential semantics
- Avoids the double exponential blow-up of exhaustive path enumeration
- However: non-deterministic

Classic top k shortest paths algorithms

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Yen [Yen 71]

- Extends shortest path computation (e.g. with Dijkstra's algorithm)
- Only works for **acyclic paths**

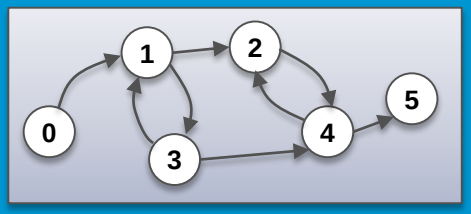
Eppstein [Eppstein 99]

- Adds support for cycles
- Memory-efficient representation of multiple paths

Main applications in routing (traffic, networks), where **weigths are essential**.

RDF graphs not weighted ⇒ unnecessary overhead.

Bidirectional BFS



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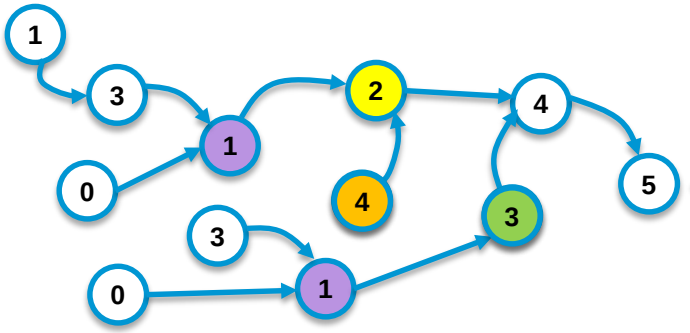
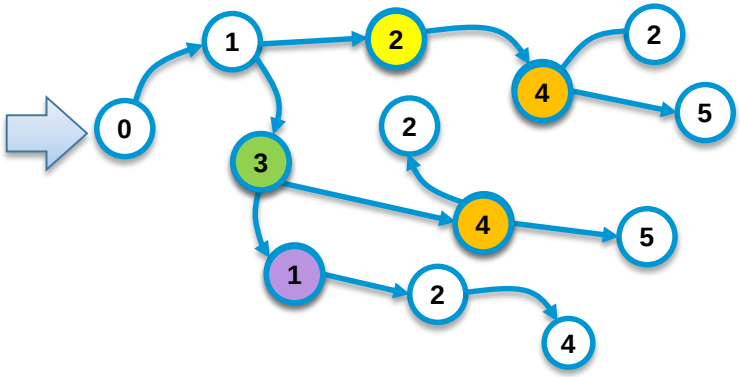
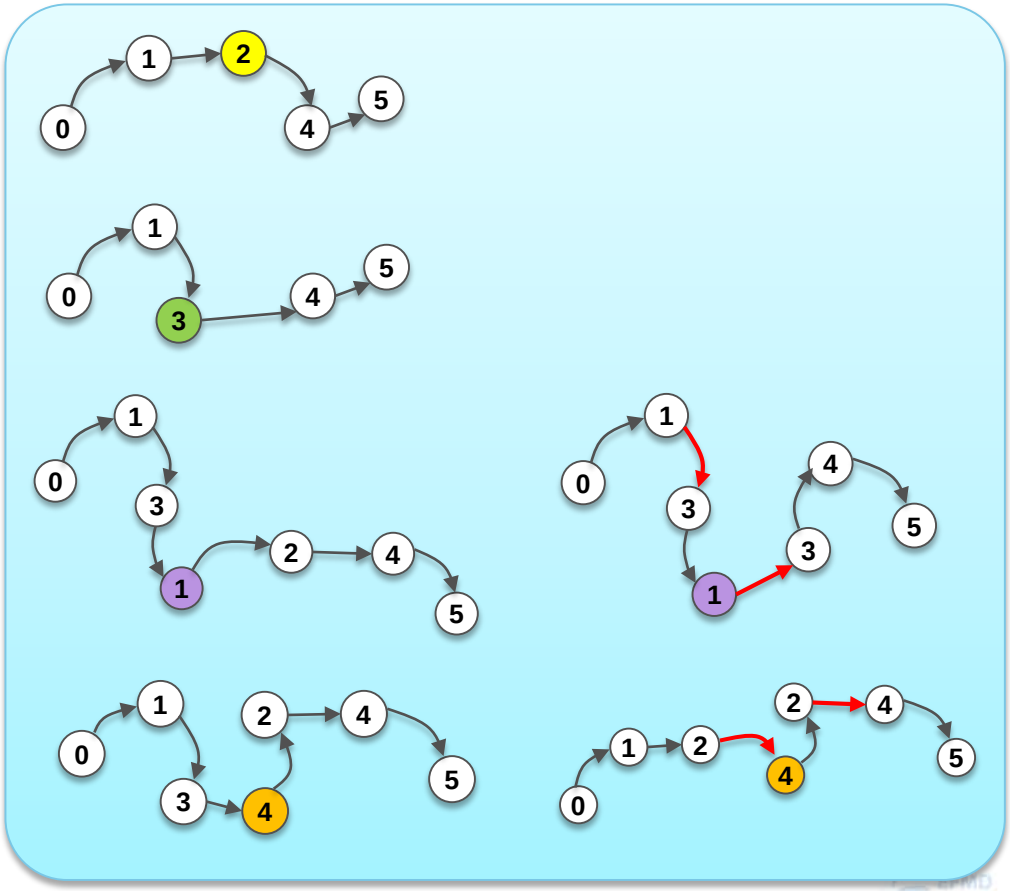
Traversals





Paths found



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Native HDT Interface

```
public interface GraphIndex<V,E> {
    Iterator<Edge<V,E>> lookupEdges(V source, V target);
    PathArbiter<V,E> createAllPassArbiter();
}

public class HDTIntGraphIndex implements GraphIndex<Integer,Integer> {
    public final HDT hdt;
    public final org.rdfhdt.hdt.dictionary.Dictionary dict;
…
  @Override
   public Iterator<Edge<Integer,Integer>> lookupEdges(Integer source, Integer target){
      if(source == null){ source = 0;  }
      if(target == null){  target = 0;    }
      TripleID tripleid = new TripleID(source, 0, target);
      IteratorTripleID result = null;
      try {
         result = hdt.getTriples().search(tripleid);
      }
      catch(IndexOutOfBoundsException ex){ }
      return result!=null? new TripleIterator(result, source.equals(0)) :
            new EmptyTripleIterator();
   }
```

Our current approach

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- Based on bi-directional BFS
- Adds support for path expressions
- Flexible implementation due to Java generics
- Packed as an extension library (Jena ARQ), currently over HDT graphs
  - fast lookups to get (outgoing/incoming) edges
  - memory efficient due to dictionary encoding IRIs and strings as integers
- Outperforms similar approaches as well as existential path queries in established commercial systems (Stardog, Blazegraph,Virtuoso)

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hdt-jena based interface

```
public class RDFGraphIndex implements GraphIndex<Node,Node> {
   …
   Graph graph;

   public RDFGraphIndex(Graph graph){
      this.graph = graph;
   }

   @Override
   public Iterator<Edge<Node, Node>> lookupEdges(Node source, Node target) {
      return new WrappingIterator(graph.find(source,null,target), source==null);
   }
```

+ Some workarouds

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```
@Override
public void init(GraphIndex<Integer,Integer> gi, Integer source, Integer target, boolean bidirectional)
{
    hdt = (HDTIntGraphIndex)gi;
    if( hdt!=null ){
        this.target = target;
        this.nShared = hdt.dict.getNshared();
    }
}

@Override
public CumulativeRank rankEdge(Edge<Integer,Integer> edge, Iterable<Edge<Integer,Integer>> path,
                               CumulativeRank pathRank, boolean forkRankObject, boolean backwardPath ){

    //A workaround for the problem that literals and IRIs can have clashing HDT integer representation.
    if( hdt!=null && !backwardPath ){
        Integer v = edge.vertex();
        if( v>=nShared && v!=target ) {
            if ( v != hdt.vertexKey(hdt.vertexEntry(v, Edge.Component.TARGET), Edge.Component.SOURCE) ){
                return pruneRank;
            }
        }
    }
    return passRank;
}
```

Adding SPARQL 1.1 Property Path Expressions to BFS

- Use dk.brics.automaton [Møller17] Java library to construct an NFA based on the path expression
- Making use of Jena ARQ path expression parser
- Encode properties as characters: a / (b/c)* /d for

  foaf:knows / (dbp:predecessor/dbp:firstWin)* / dbp:parent
- For the backward search, recursively invert all sequences:

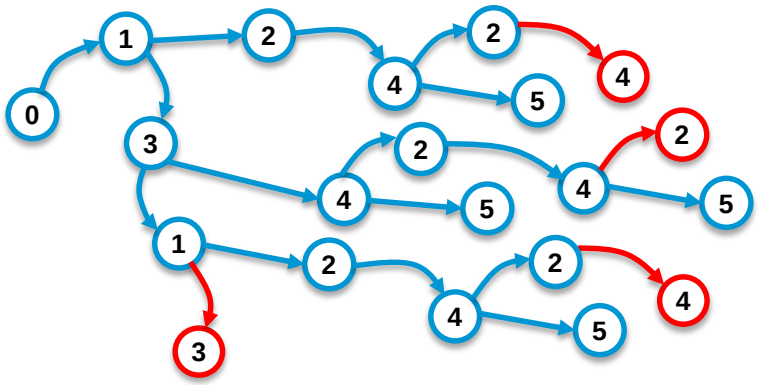
  a / (b/c)* /d ⇒ d / (c/b)* /a
- Inverse paths (e.g.: ^dbp:predecessor) currently unsupported

Path expressions

At evaluation time:

- Same IRI-to-character dictionary + special fresh character for all properties not metnioned in the expression

- Each node in the unfolding tree contatins the NFA state for early path prunning



Syntax

- Use Jena ARQ property functions (allowing for side-effects, e.g. querying the graph store and modifying the number of results)

```
PREFIX : <http://dbpedia.org/property/>
PREFIX dbr: <http://dbpedia.org/resource/>
PREFIX ppf: <java:at.ac.wu.arqext.path.>
SELECT ?path WHERE {
    ?path ppf:topk (dbr:Felipe_Massa dbr:Red_Bull 10
    ":firstWin/((!:)*)|(!:)*/:firstWin") }
```

- `(!:)` is a wildcard (negation of a non-existant empty IRI)
- ?path contains paths represented as concatenated strings
- **Source and target nodes need to be bound in the query**

Evaluation Setup

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Based on DBpedia SPARQL Benchmark [Morsey et al. 11], as used in the ESWC 2016 Top k Shortest Paths Challenge [Papadakis et al. 16]

	Triples	Subjects	Pred's	Objects	Shared
0.1DB	9 264 609	313 036	13 114	3 482 820	58 535
1DB	46 275 619	1 457 983	21 875	13 751 780	462 478

Queries (with k varying from 3 to 400K)

Optional restriction on the first OR the last edge

ID	Source node (dbr:)	Target node (dbr:)	Property (dbp:)
Q1	Felipe_Massa	Red_Bull	firstWin
Q2	1952_Winter_Olympics	Elliot_Richardson	after
Q3	Karl_W._Hofmann	Elliot_Richardson	predecessor
Q4	Karl_K._Polk	Felix_Grundy	president

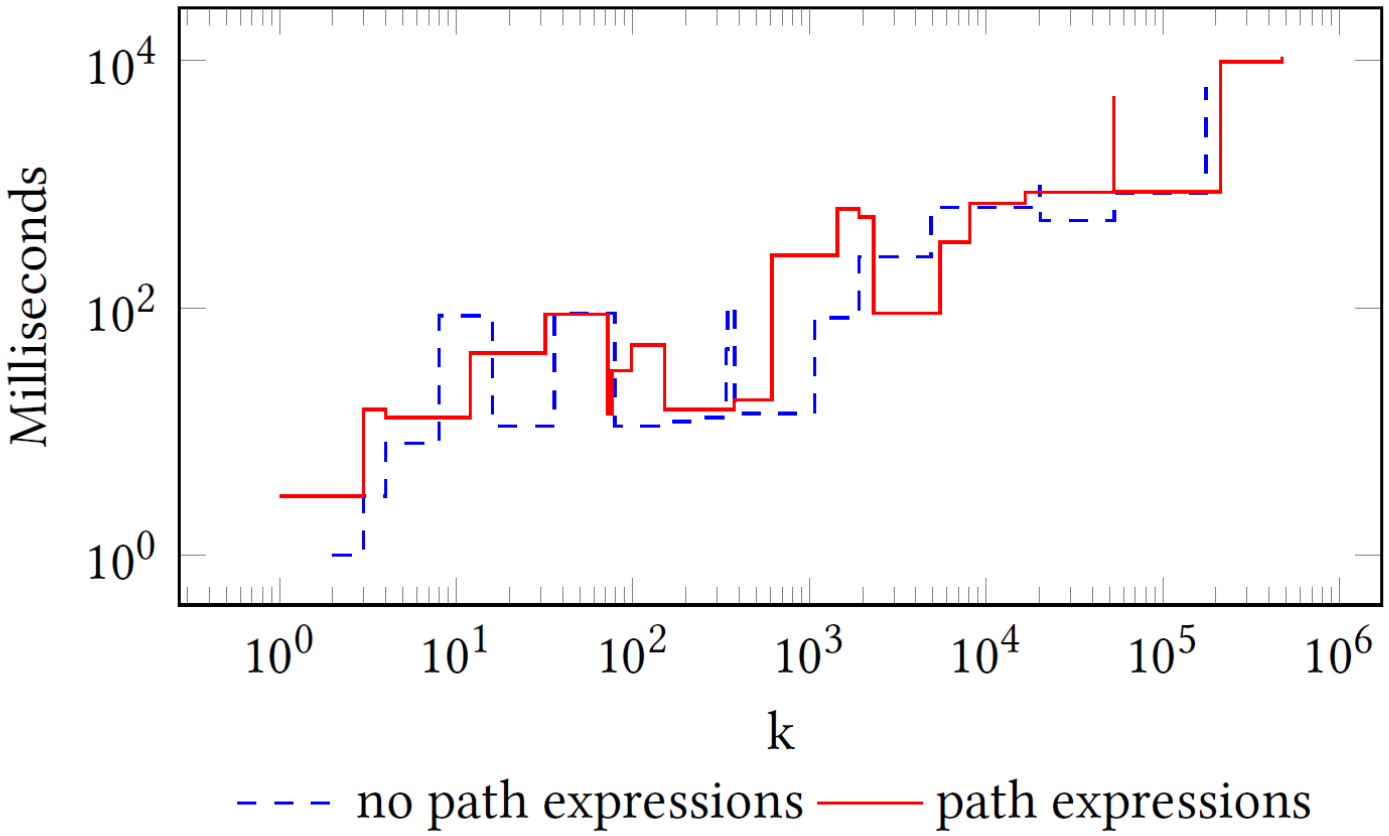
Comparing against Stardog

Query	$k = 1$	$k = 100$	Stardog (reachability)
Q1 (!:*)	24	94	57
Q1	125	6 138	19,732
Q2 (!:*)	15	132	45
Q2	19	2 568	34 707

Performance of top k / reachability queries

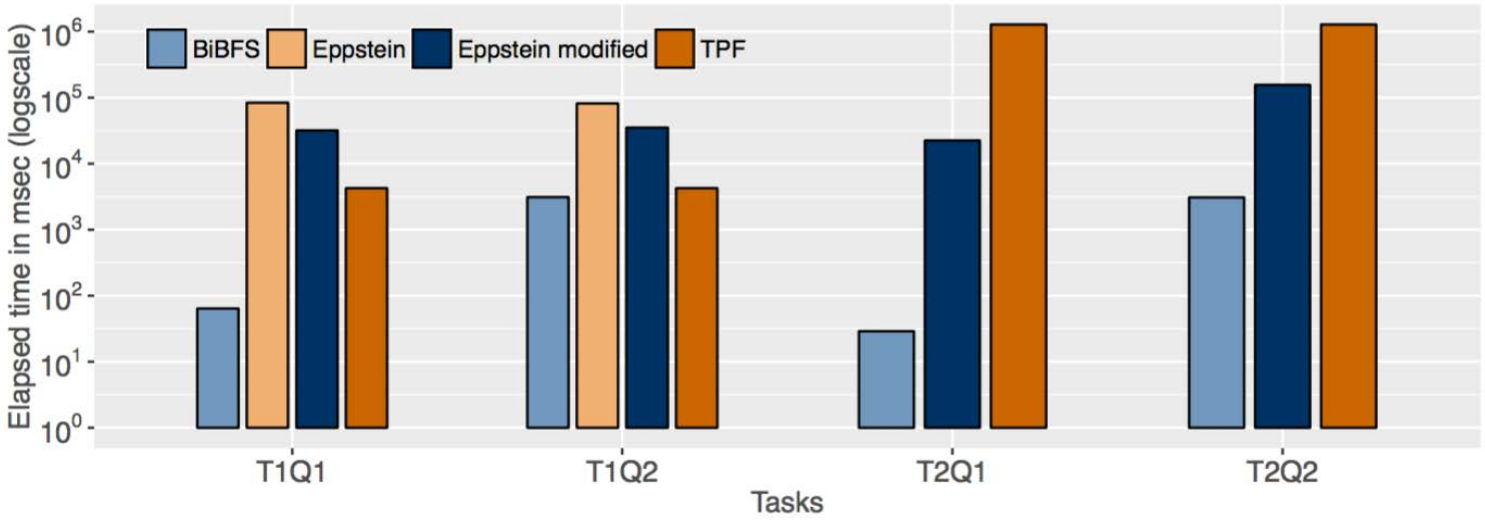
Blazegraph and Virtuoso did not deliver results (no results, or memory limits hit).

Path expressions support is inexpensive



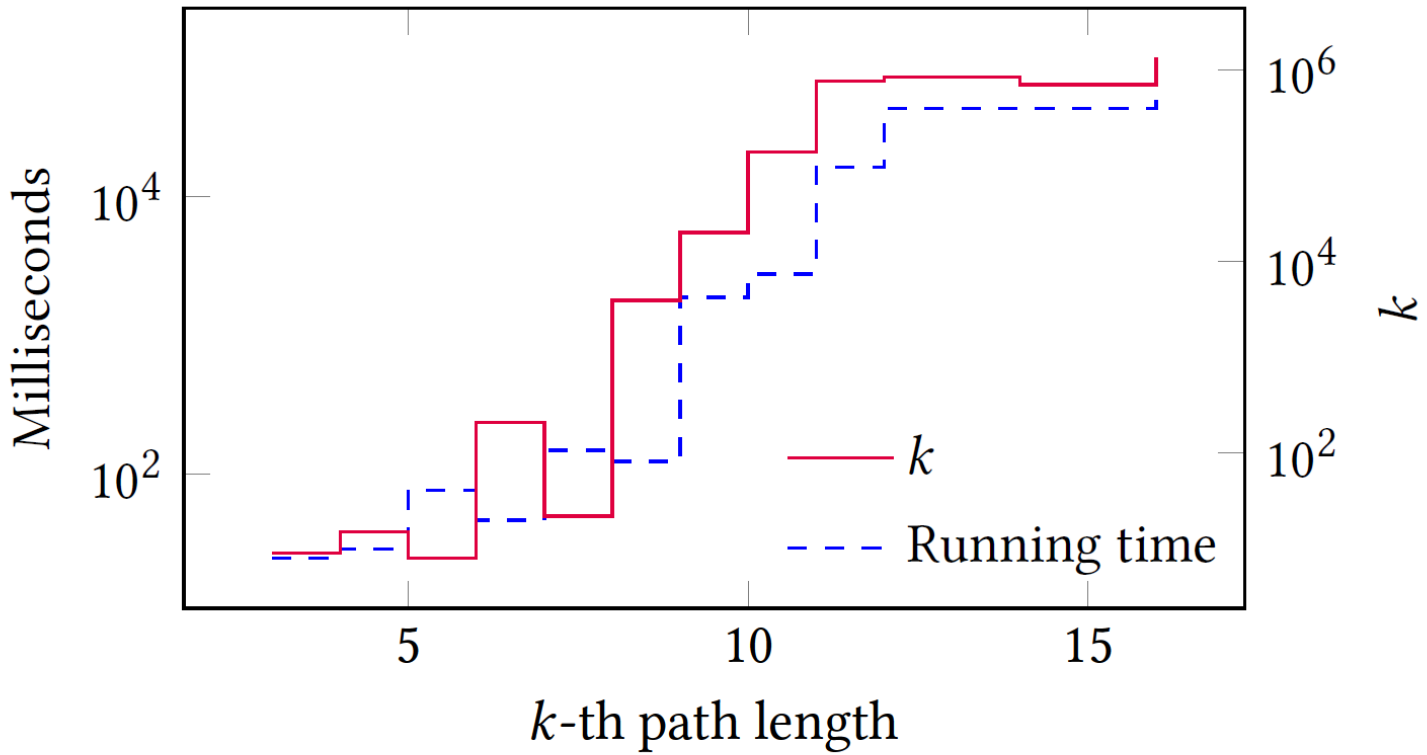
Comparison against the ESWC 2016 challenge finalists

- **Eppstein**: dataset modification: no multi-edges, all weights =1
- Reported runtimes from
  - [Hertling et al.16] (**Eppstein modified**)
  - [De Vocht et al.16] (**TPF)** Triple pattern fragments



Experiment: Random paths

- Random walk to ensure connectivity with a given path length
- Increase k to ensure that the desired path length is hit



Conclusion

- Memory intensive BFS can be adapted to find top-k shortest paths in RDF graphs using HDT compression.
- Path expressions do not incur significant costs.
- Simple and easily extensible approach.

Future Work

- Support more SPARQL engines via appropriate extension interfaces
- Support special indexes for reachability.
- Paths in federated queries?

Thank you!

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More information https://iktderzukunft.at/en/

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Literature

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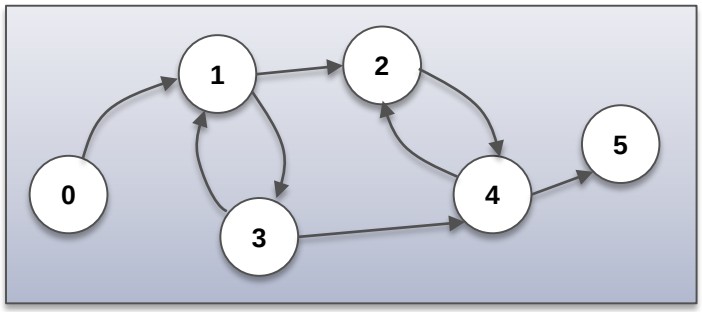
[De Vocht et al.16] De Vocht, L., Verborgh, R., Mannens, E., Van de Walle, R.: Using Triple Pattern Fragments to Enable Streaming of Top-k Shortest Paths via the Web. ESWC 2016 Challenges

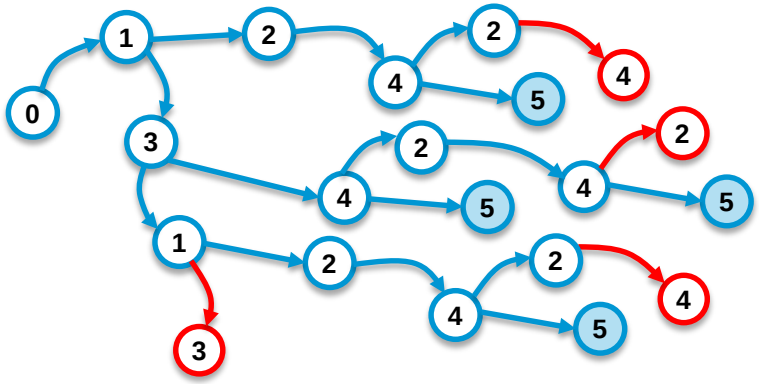
[Yen 71] J. Y. Yen, "Finding the K Shortest Loopless Paths in a Network," Management Science, 17 (11), pp. 712–716, 1971.

BFS for shortest path enumeration

- **Unfolding** the graph into a tree starting with a given node



Assuming all properties be the same in this example



Disallow exactly repeated edges (n_1, p, n_2) in paths.

That is, enumerate *trails*

The tree allows for reuse of common path prefixes