Graceful Operations in Link-State Routing Protocols

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Some context

- Intra-domain routing in IP networks;
  - Link-state protocols (OSPF, IS-IS) possibly running MPLS with LDP;
- Frequent topological changes;
  - Maintenance operations on links or nodes;
  - Traffic engineering (weight modifications);

  ▷ Possible extension: unplanned changes;
- . . . and as many convergence periods;
  - Inconsistent transient state;
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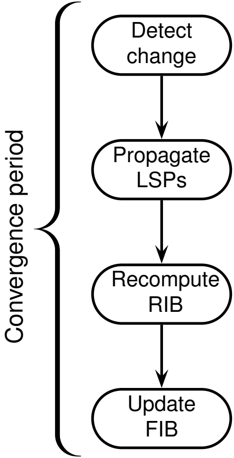


1. Introduction
2. Transient loops
3. Node shut
4. Conclusion

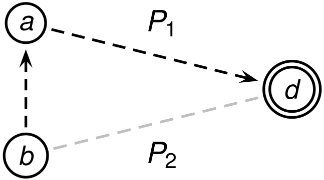
How do transient loops appear?

Routers' update order is **not controlled**!
(depends on *LSA flooding* and *RIB/FIB update* times)

Example:

- Initially, both *a* and *b* reach *d* through *a*;

Routes towards *d*:



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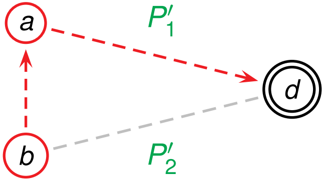

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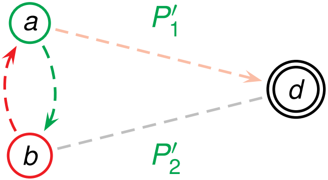

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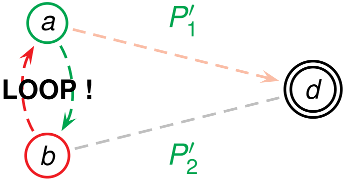

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  - ▷ Increased latency;
  - ▷ Packet losses.

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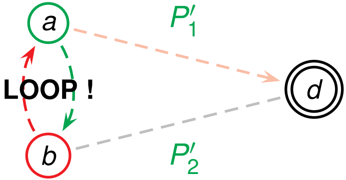

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Force the routers to update in the *right* order.

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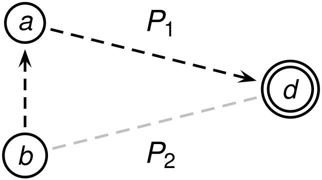

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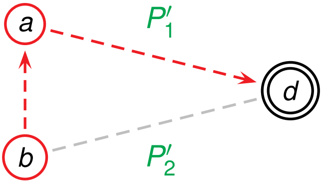

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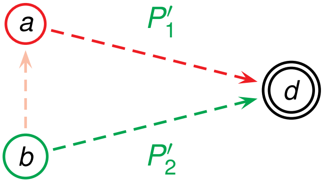

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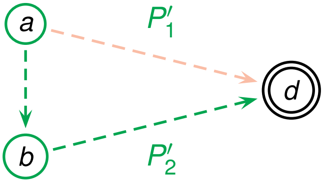

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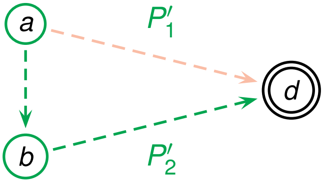
One goal, several approaches.



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Related works

- Ordered FIB *[INFOCOM'05, TON'07]*
  - Explicit router update ordering;
  - Relies on protocol extensions;
  - Non-incremental deployment;
- IGP migration *[SIGCOMM'12]*
  - Designed for network-wide migrations;
  - Requires to maintain two concurrent control planes;
  - Huge overhead for single link or node modifications;
- Metric increment - Link shut *[INFOCOM'07, TON'13]*
  - Progressive link weight update;
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Progressive update

Basic idea

Split up the change into a sequence of **loop free** updates.

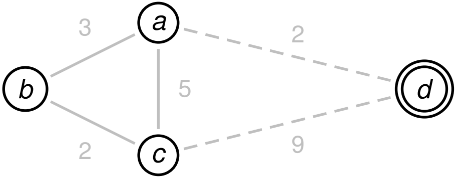
Objectives

Compute a sequence of intermediate updates, such that there is no transient loop between subsequent updates.

Challenge

- Sequences of minimal length (minimal operational impact);
- Efficient algorithm (embedded in router OS).

Illustration: path increment sequence



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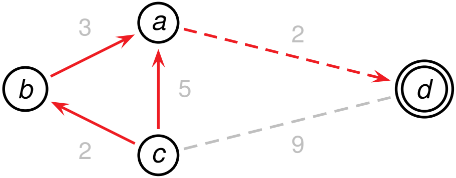

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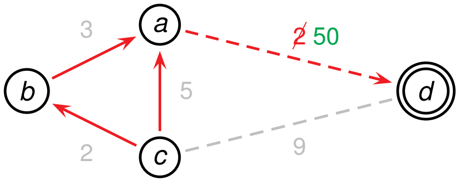

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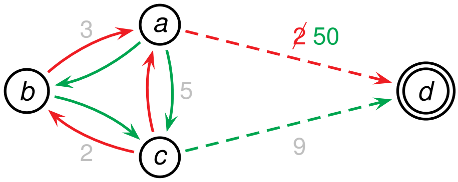

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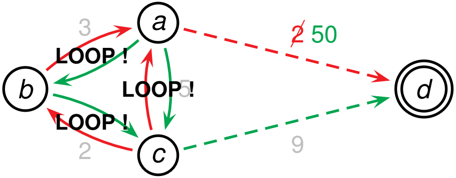

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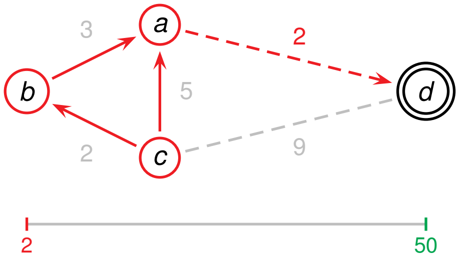

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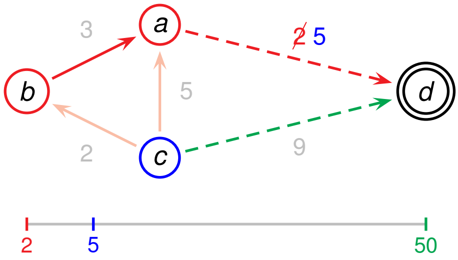

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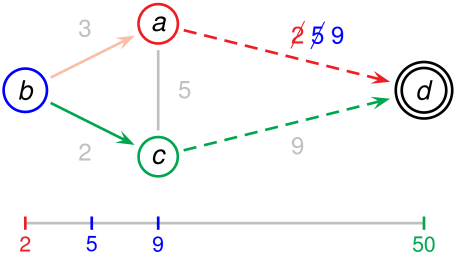

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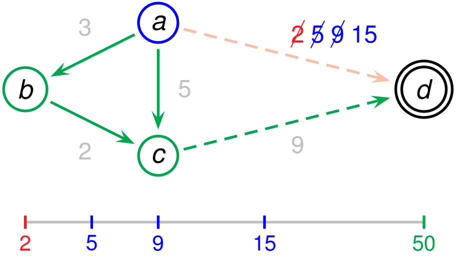

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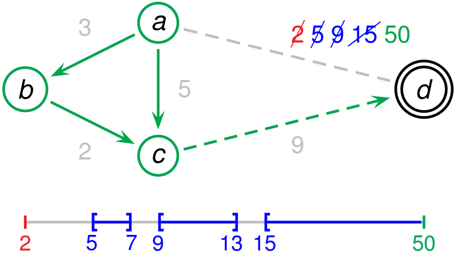
So that the transition to 50 will be loop free **for destination** *d*.



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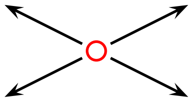

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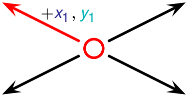

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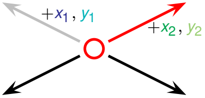

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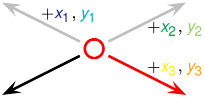

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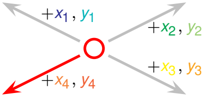

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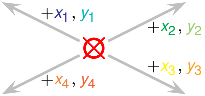

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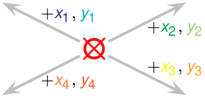

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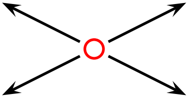

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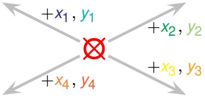

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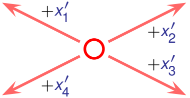

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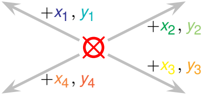

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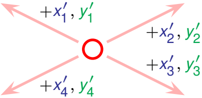

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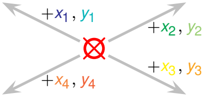

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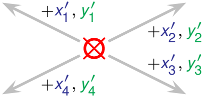
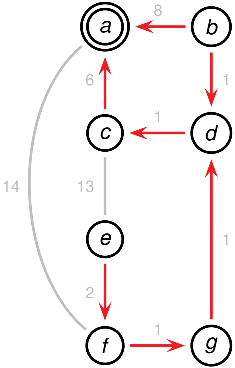


2 intermediate steps

Towards Multi-Dimensional Increments



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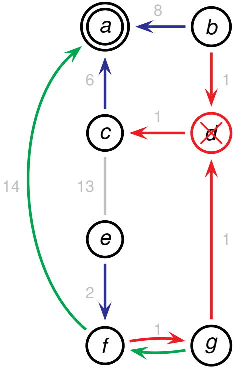

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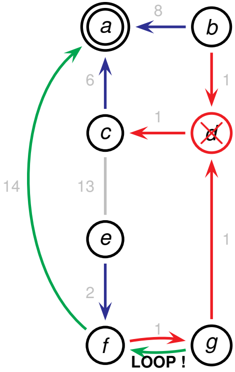

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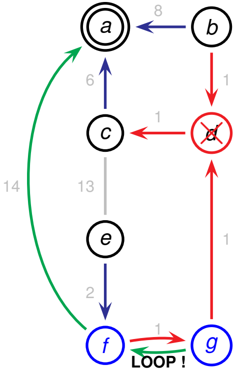

Vector of minimum increments such that a node x uses a new path, not through n, to reach d.

$$\Delta_d^n(x)[i] = C'(x,d) - C(x,i,d)$$

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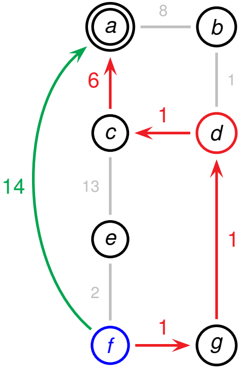

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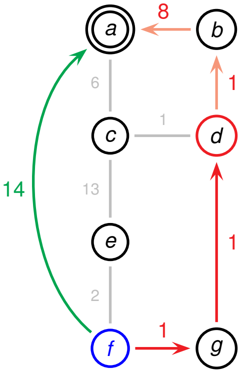

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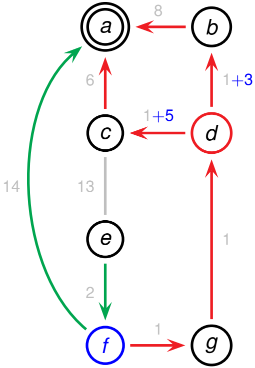

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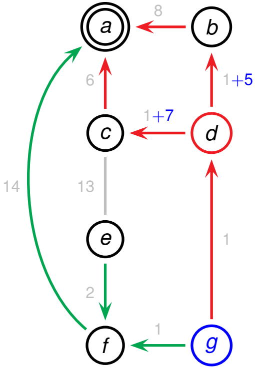
- $\Delta_a^d(f) = \begin{pmatrix} 14 - (1+1+1+6) \\ 14 - (1+1+1+8) \end{pmatrix} = \begin{pmatrix} 5 \\ 3 \end{pmatrix}$

Towards Multi-Dimensional Increments

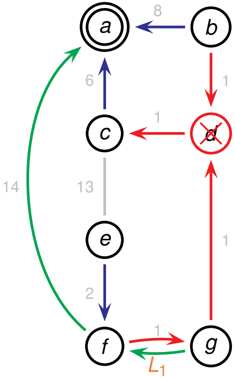


Vector of minimum increments such that a node x uses a new path, not through n, to reach d.

$$\Delta_d^n(x)[i] = C'(x,d) - C(x,i,d)$$

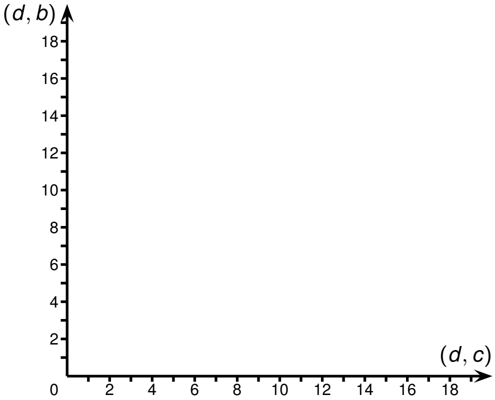
- $\Delta_a^d(f) = \begin{pmatrix} 14 - (1+1+1+6) \\ 14 - (1+1+1+8) \end{pmatrix} = \begin{pmatrix} 5 \\ 3 \end{pmatrix}$
- $\Delta_a^d(g) = \begin{pmatrix} 15 - 8 \\ 15 - 10 \end{pmatrix} = \begin{pmatrix} 7 \\ 5 \end{pmatrix}$

Modeling Loops as Vectorial Constraints



$$\Delta_a^d(f) = \begin{pmatrix} 5 \\ 3 \end{pmatrix}$$

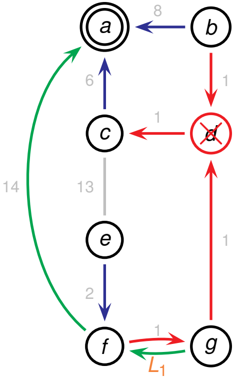
$$\Delta_a^d(g) = \begin{pmatrix} 7 \\ 5 \end{pmatrix}$$



Constraint c associated to a given a loop L.

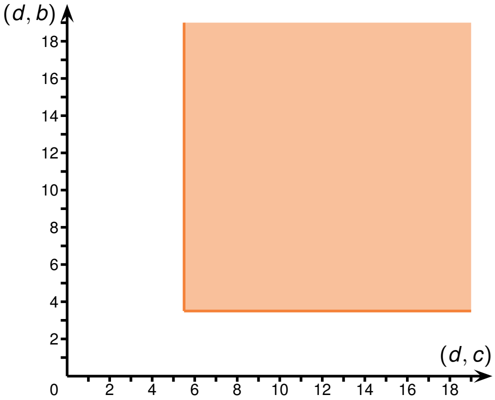
$$c := (\min_{\forall x \in L}(\Delta(x)), \max_{\forall x \in L}(\Delta(x)))$$

Modeling Loops as Vectorial Constraints



$$\Delta_a^d(f) = \begin{pmatrix}5\\3\end{pmatrix}$$

$$\Delta_a^d(g) = \begin{pmatrix}7\\5\end{pmatrix}$$

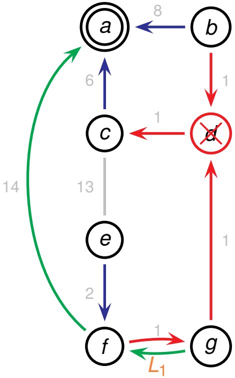


Constraint c associated to a given a loop L.

$$c := (\min_{\forall x \in L}(\Delta(x)), \max_{\forall x \in L}(\Delta(x)))$$

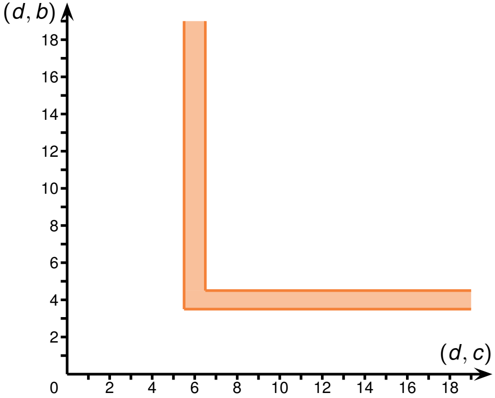
$$c_1 = \left(\begin{pmatrix}5\\3\end{pmatrix}\right)$$

Modeling Loops as Vectorial Constraints



$$\Delta_a^d(f) = \begin{pmatrix} 5 \\ 3 \end{pmatrix}$$

$$\Delta_a^d(g) = \begin{pmatrix} 7 \\ 5 \end{pmatrix}$$

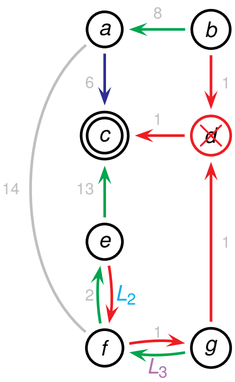


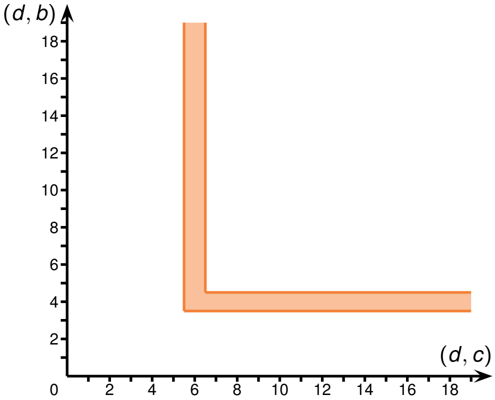
Constraint c associated to a given a loop L.

$$c := (\min_{\forall x \in L}(\Delta(x)), \max_{\forall x \in L}(\Delta(x)))$$

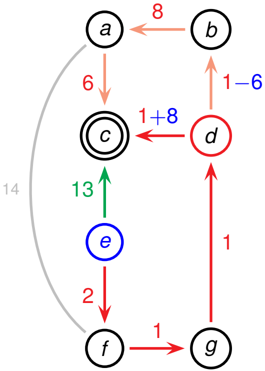
$$c_1 = \left(\begin{pmatrix} 5 \\ 3 \end{pmatrix}, \begin{pmatrix} 7 \\ 5 \end{pmatrix} \right)$$

Modeling Loops as Vectorial Constraints (2)

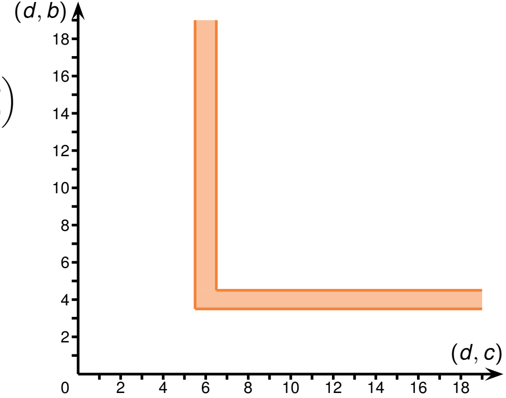




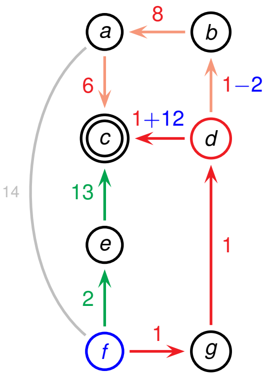
Modeling Loops as Vectorial Constraints (2)



$$\Delta_2^3(e) = \begin{pmatrix} 8 \\ 0 \end{pmatrix}$$

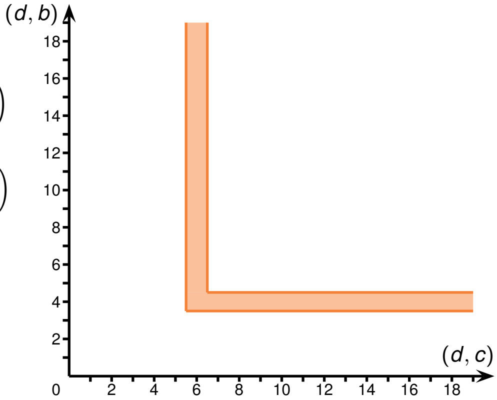


Modeling Loops as Vectorial Constraints (2)

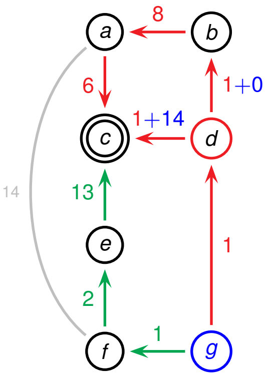


$$\Delta_2^3(e) = \begin{pmatrix} 8 \\ 0 \end{pmatrix}$$

$$\Delta_2^3(f) = \begin{pmatrix} 12 \\ 0 \end{pmatrix}$$



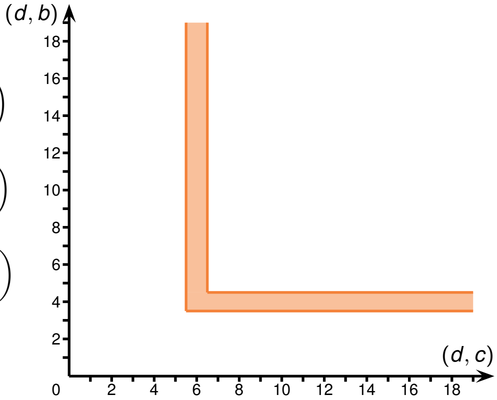
Modeling Loops as Vectorial Constraints (2)



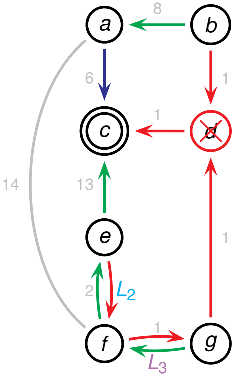
$$\Delta_2^3(e) = \begin{pmatrix} 8 \\ 0 \end{pmatrix}$$

$$\Delta_2^3(f) = \begin{pmatrix} 12 \\ 0 \end{pmatrix}$$

$$\Delta_2^3(g) = \begin{pmatrix} 14 \\ 0 \end{pmatrix}$$



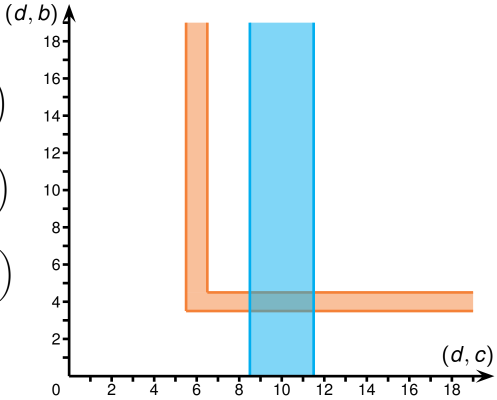
Modeling Loops as Vectorial Constraints (2)



$$\Delta_2^3(e) = \begin{pmatrix} 8 \\ 0 \end{pmatrix}$$

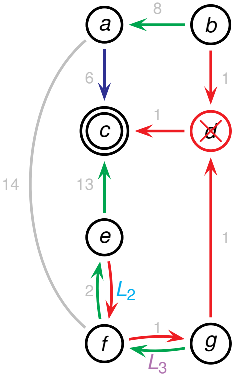
$$\Delta_2^3(f) = \begin{pmatrix} 12 \\ 0 \end{pmatrix}$$

$$\Delta_2^3(g) = \begin{pmatrix} 14 \\ 0 \end{pmatrix}$$



$$c_2 = \left(\begin{pmatrix} 8 \\ 0 \end{pmatrix}, \begin{pmatrix} 12 \\ 0 \end{pmatrix} \right)$$

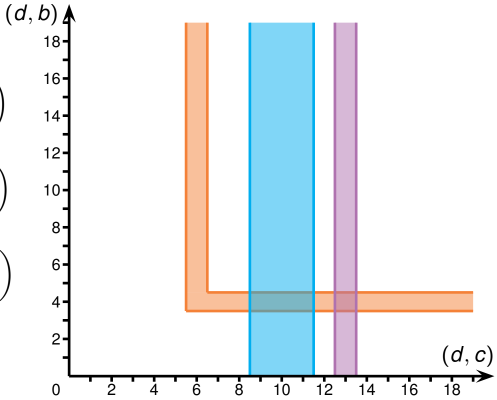
Modeling Loops as Vectorial Constraints (2)



$$\Delta_2^3(e) = \begin{pmatrix} 8 \\ 0 \end{pmatrix}$$

$$\Delta_2^3(f) = \begin{pmatrix} 12 \\ 0 \end{pmatrix}$$

$$\Delta_2^3(g) = \begin{pmatrix} 14 \\ 0 \end{pmatrix}$$

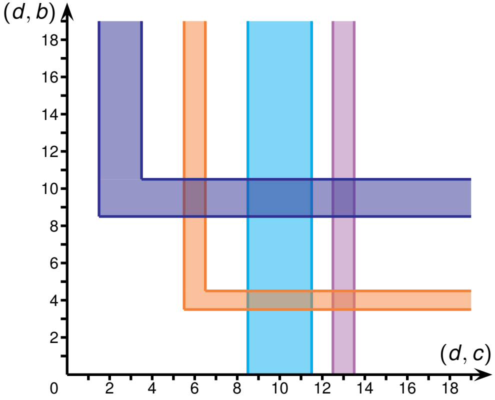


$$c_2 = \left(\begin{pmatrix} 8 \\ 0 \end{pmatrix}, \begin{pmatrix} 12 \\ 0 \end{pmatrix} \right)$$

$$c_3 = \left(\begin{pmatrix} 12 \\ 0 \end{pmatrix}, \begin{pmatrix} 14 \\ 0 \end{pmatrix} \right)$$

Modeling Loops as Vectorial Constraints (3)

$$c_4 = \left(\begin{pmatrix} 1 \\ 8 \end{pmatrix}, \begin{pmatrix} 4 \\ 11 \end{pmatrix} \right)$$

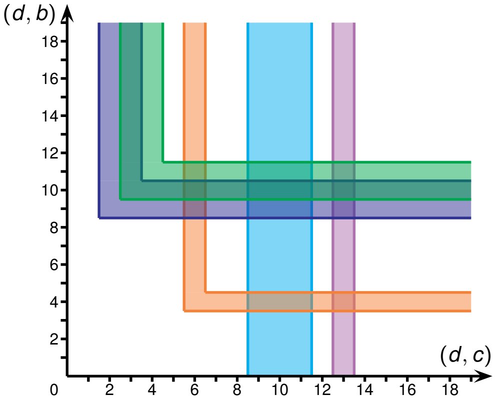


An update sequence s avoids a loop L if and only if s contains at least one vector meeting the corresponding constraint.

Modeling Loops as Vectorial Constraints (3)

$$c_4 = \left(\begin{pmatrix} 1 \\ 8 \end{pmatrix}, \begin{pmatrix} 4 \\ 11 \end{pmatrix} \right)$$

$$c_5 = \left(\begin{pmatrix} 2 \\ 9 \end{pmatrix}, \begin{pmatrix} 5 \\ 12 \end{pmatrix} \right)$$

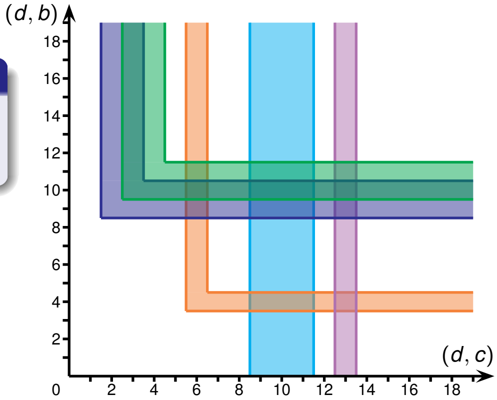


An update sequence s avoids a loop L if and only if s contains at least one vector meeting the corresponding constraint.

Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

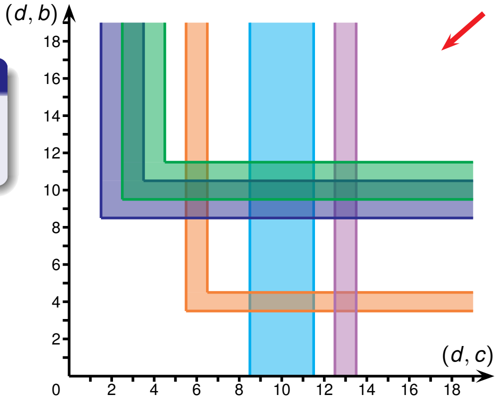


Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

Sequence:

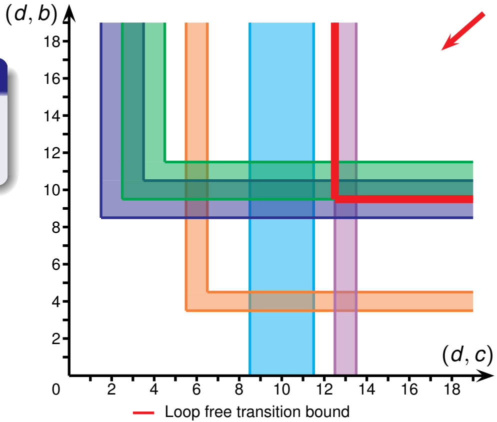


Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

Sequence:



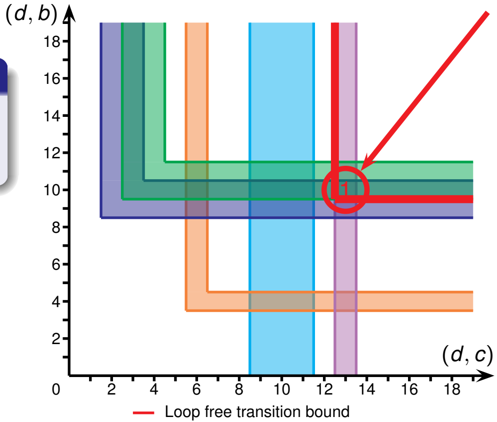
Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

Sequence:

1. C_3, C_4, C_5



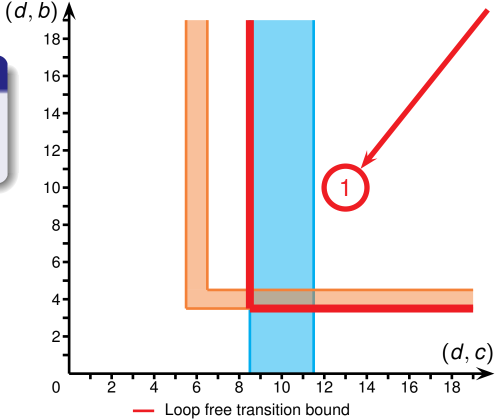
Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

Sequence:

1. C_3, C_4, C_5



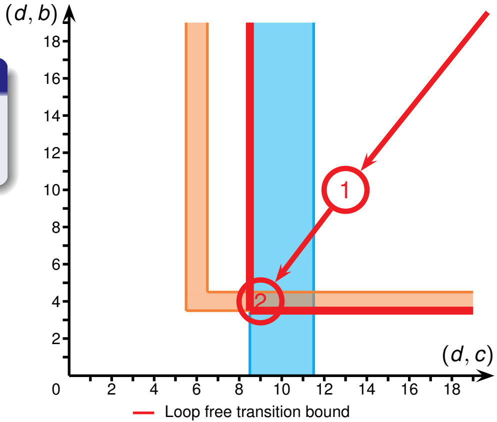
Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

Sequence:

1. C_3, C_4, C_5
2. C_1, C_2



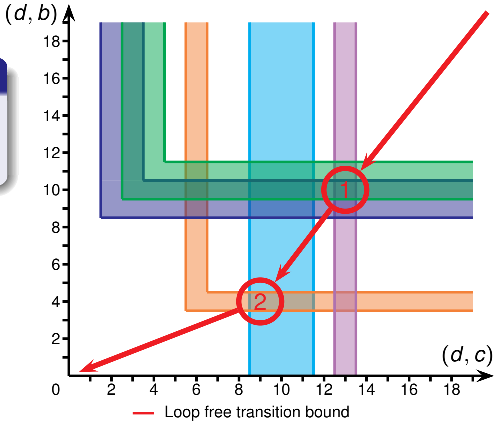
Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

Sequence:

1. C_3, C_4, C_5
2. C_1, C_2



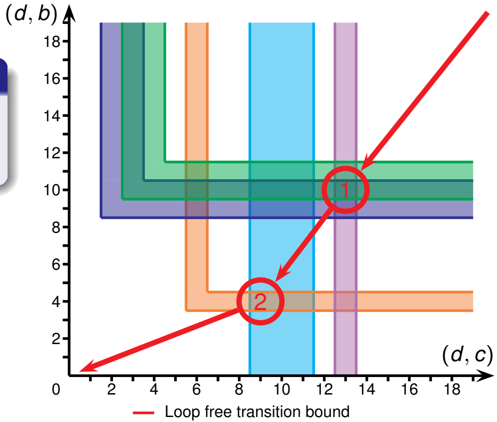
Defining Safe Weight Increment Sequences

Greedy Backward Algorithm (GBA)

At each step, retrieve the maximum value on each index among the lower bounds of the remaining constraints.

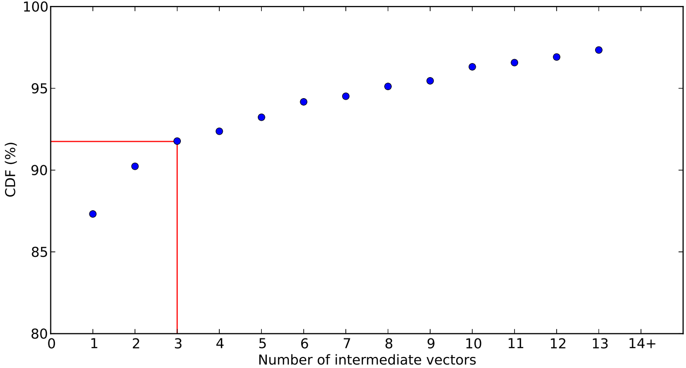
Sequence:

1. C_3, C_4, C_5
2. C_1, C_2



Given a set of loop-constraints, GBA computes a minimal sequence of intermediate increments preventing convergence loops.

Sequence Lengths on a Real ISP Network



- Graph with more than 1000 nodes and 4000 links;
- 90% of the nodes requiring at most 3 intermediate steps.

Conclusion

- Minimal solution;
- Time efficient algorithm;
- Generic approach;

Conclusion

- ✓ Minimal solution;
  - ▷ Shortest possible sequences;
- Time efficient algorithm;
- Generic approach;

Conclusion

- ✓ Minimal solution;
  - ▷ Shortest possible sequences;
- ✓ Time efficient algorithm;
  - ▷ Polynomial complexity;
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Conclusion

- ✓ Minimal solution;
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- ✓ Generic approach;
  - ▷ Covers the single link problem.

Conclusion

- ✓ Minimal solution;
  - ▷ Shortest possible sequences;
- ✓ Time efficient algorithm;
  - ▷ Polynomial complexity;
- ✓ Generic approach;
  - ▷ Covers the single link problem.

Future works

- ▷ Implementation in Quagga;
- ▷ Evaluation in a real network.

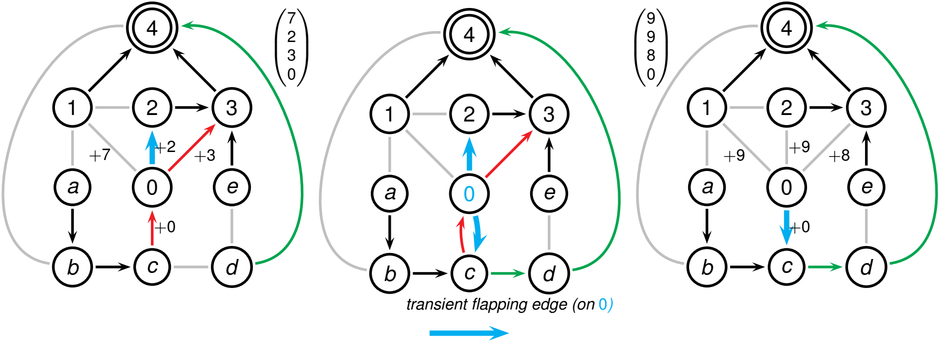
Thank you for your attention.

5 Appendix

Transient loop induced by route flapping

$\rightarrow$ $RSPDAG_1(4)$
Intermediate routing state towards 4 considering the first vector

$\rightarrow$ $RSPDAG_2(4)$
Intermediate routing state towards 4 considering the second vector



$S_{GBA} = \begin{pmatrix}7\\2\\3\\0\end{pmatrix}, \begin{pmatrix}9\\9\\8\\0\end{pmatrix}$

$S_{FF1} = \begin{pmatrix}3\\2\\3\\0\end{pmatrix}, \begin{pmatrix}7\\4\\5\\0\end{pmatrix}, \begin{pmatrix}9\\9\\8\\0\end{pmatrix}$ $S_{FF2} = \begin{pmatrix}7\\2\\3\\0\end{pmatrix}, \begin{pmatrix}9\\9\\8\\3\end{pmatrix}$