LIP6 25 septembre 2015

COMPACT ROUTING

Main results and techniques

LaBRI - Université de Bordeaux - CNRS

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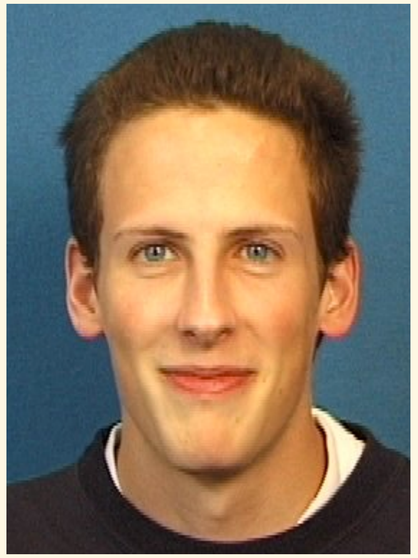


Road map

- Models and results.
- How to build a compact routing scheme.
- Compact routing in internet-like graphs.

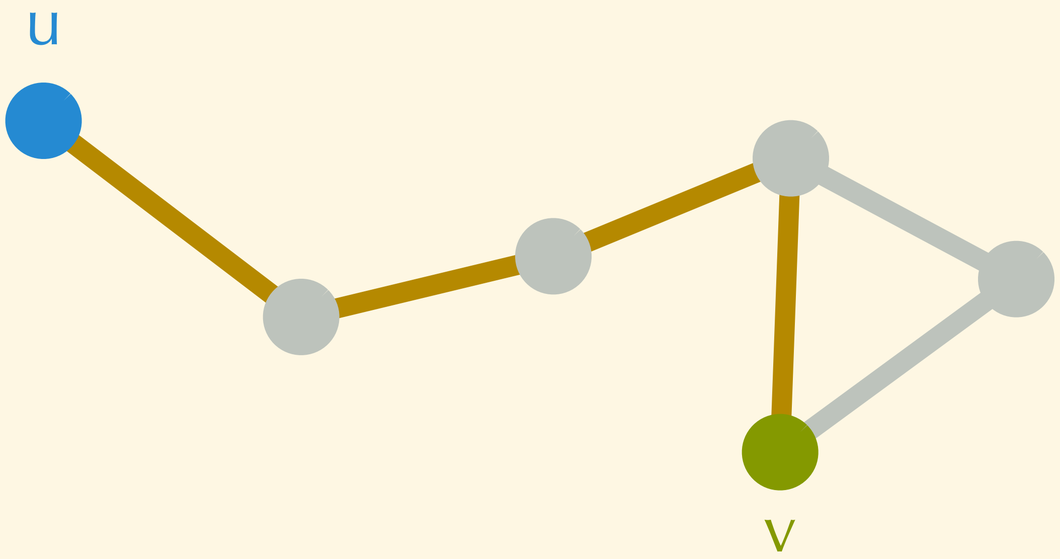
COMPACT ROUTING

What is compact routing, why does it exist ?

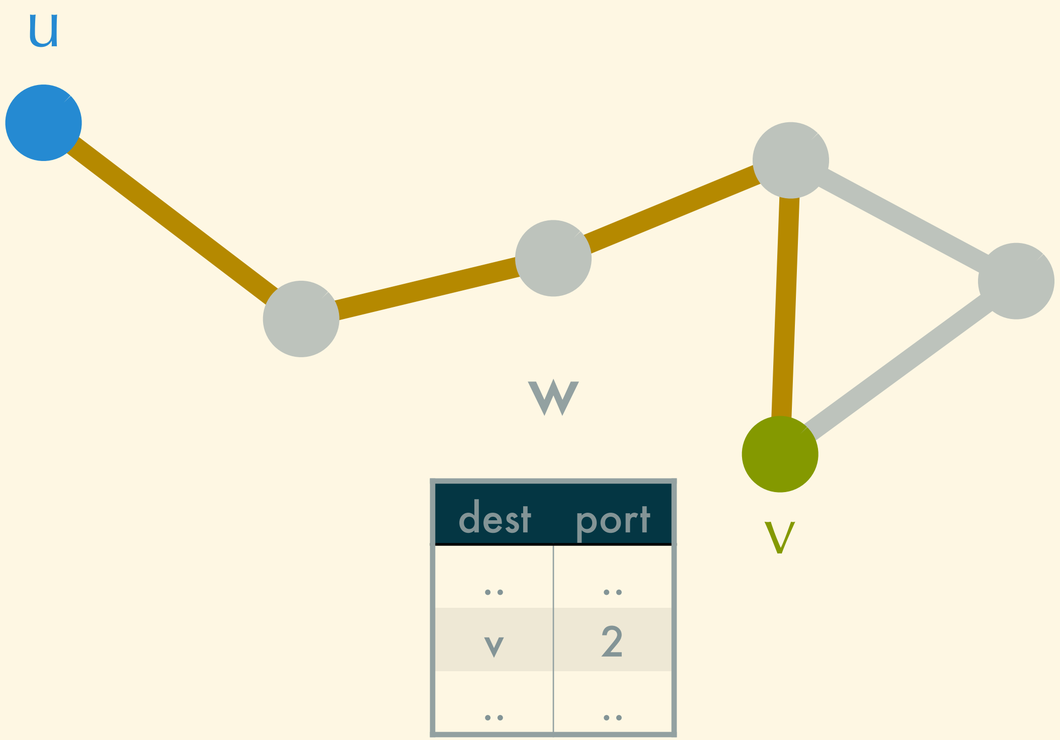
Motivations for compact routing

- Routing in large scale networks
  - having better scaling capabilities
  - forward packets faster
  - maintain routing tables up to date efficiently
- May help to save energy

Memory-Stretch Tradeoff



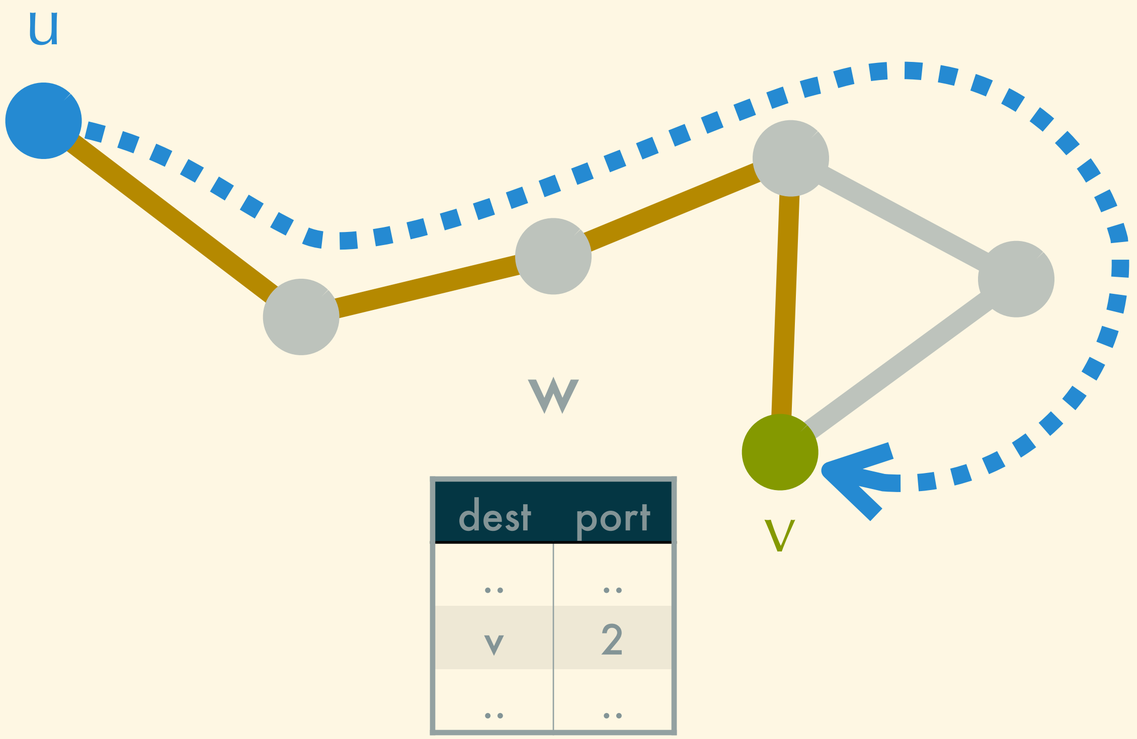
MEMORY-STRETCH TRADEOFF



MEMORY

entries stored per node

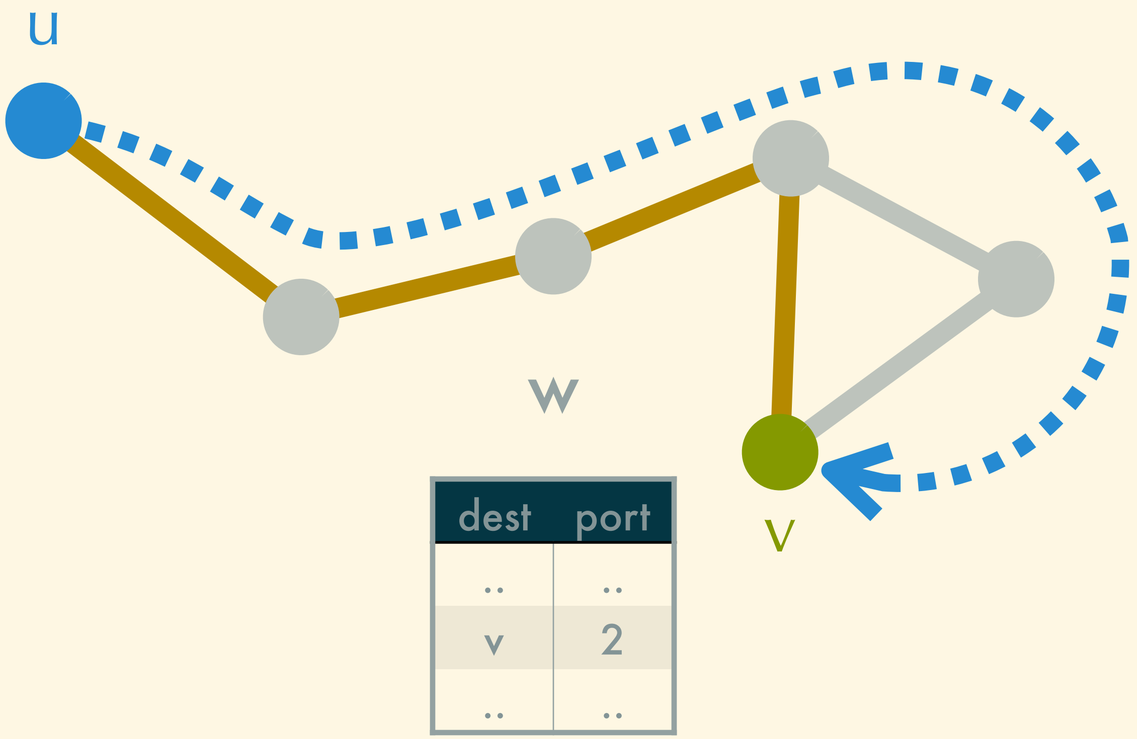
Memory-Stretch Tradeoff



Memory

entries stored per node

Memory-Stretch Tradeoff



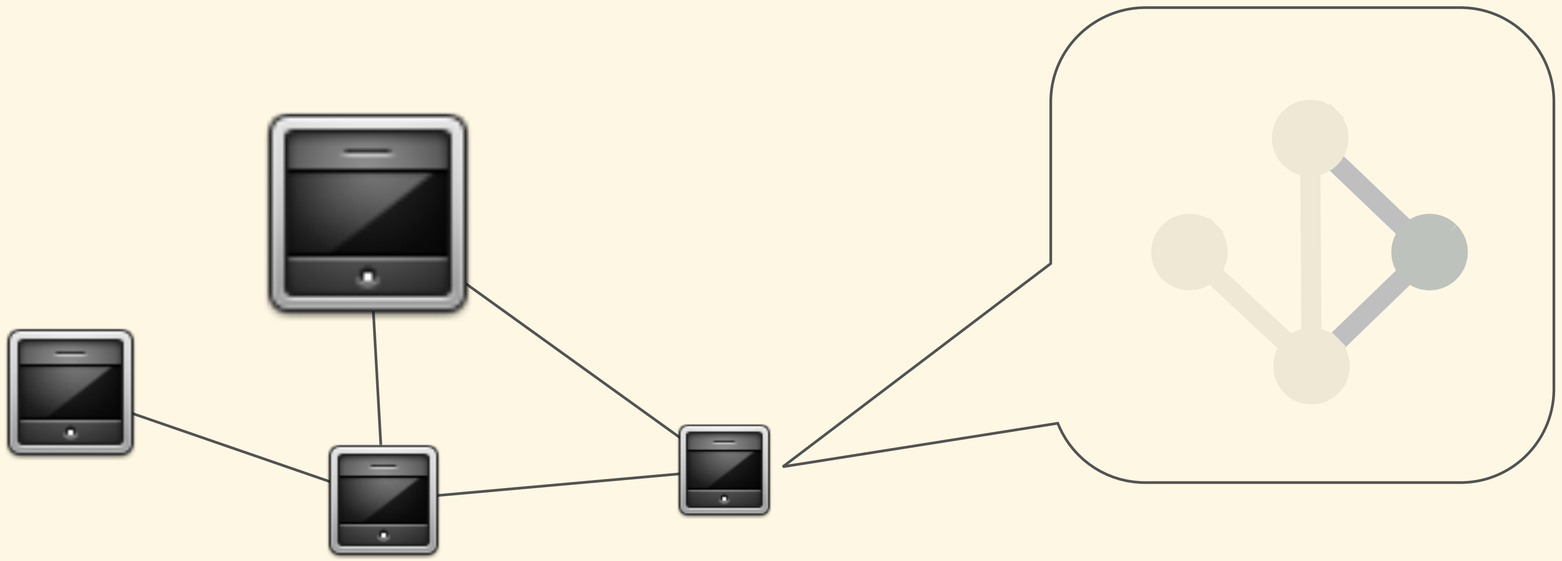
Route length (u,v) = 5
Distance (u,v) = 4

Stretch (u,v) = 5/4

Memory
entries stored per node

Stretch
maximal stretch over all pairs

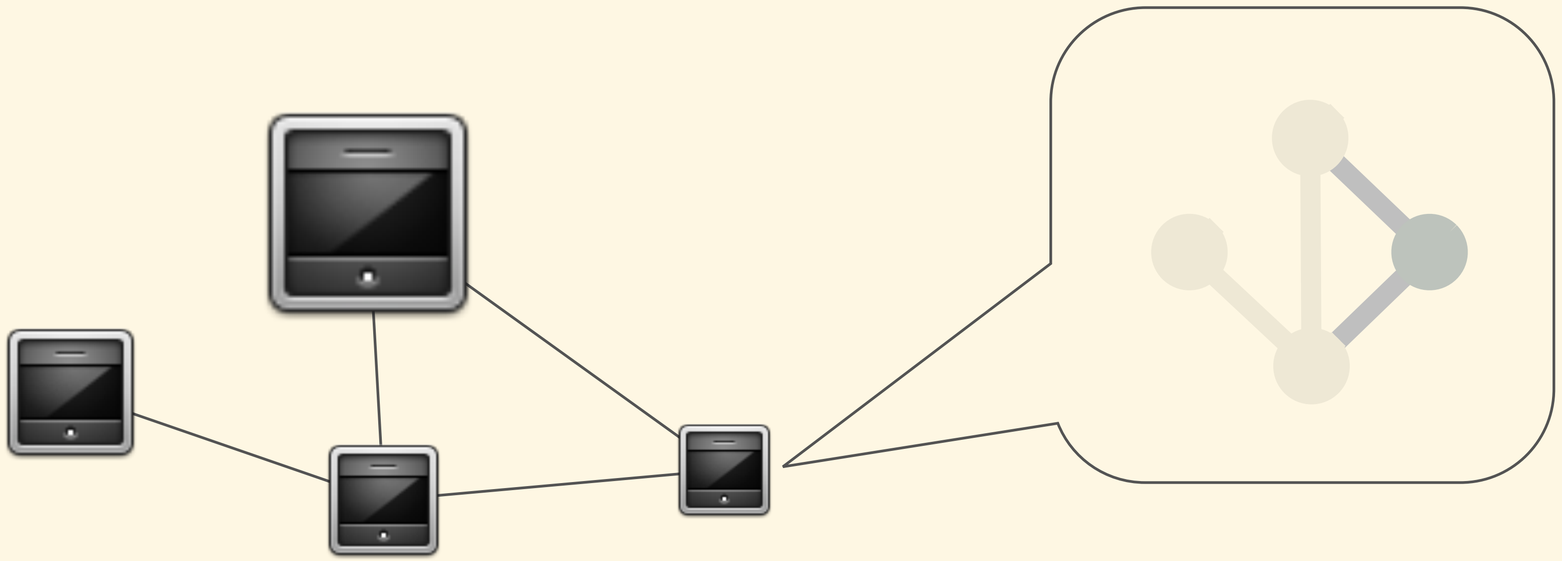
DISTRIBUTED ROUTING



Partial knowledge of
the graph (local)

⇒ need of communication
to compute routing tables

DISTRIBUTED ROUTING



Partial knowledge of
the graph (local)

⇒ need of communication
to compute routing tables

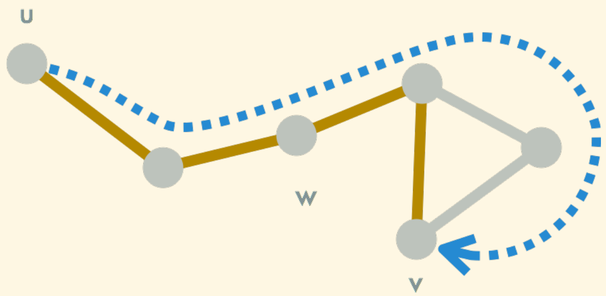
COMMUNICATION COST

of *small** messages exchanged

*polylogarithmic in the size of the network

Compact Routing

Stretch



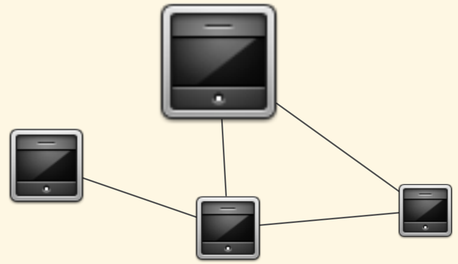
- Increased latency
- Increased energy consumption

Memory

dest	port
..	..
w	2
..	..

- Forwarding packets faster
- Saving energy

Communication cost



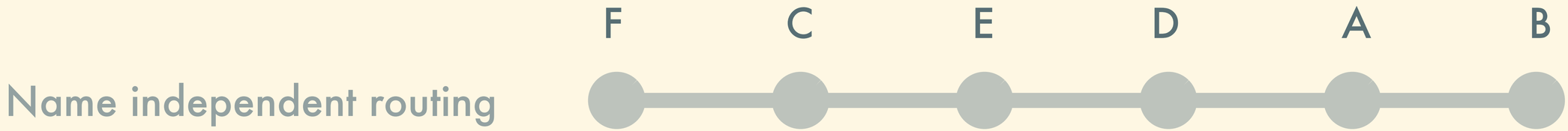
- Cost efficient maintenance
- Saving energy

Name-independent vs. Labeled

- Two models are considered for nodes naming (addresses)
  - Name-independent routing: use arbitrary routing addresses
  - Labeled routing: the designer chooses nodes' names

Name-independent vs. Labeled

The short answer



Name-independent vs. Labeled

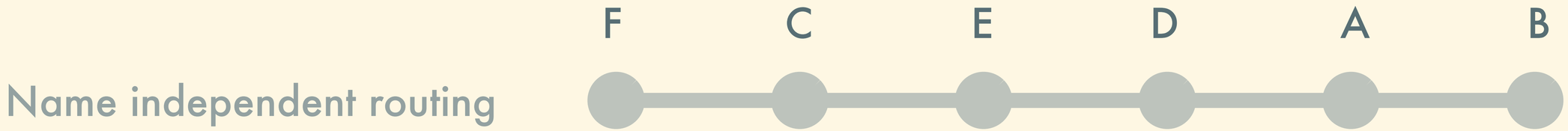
The short answer

Name independent routing

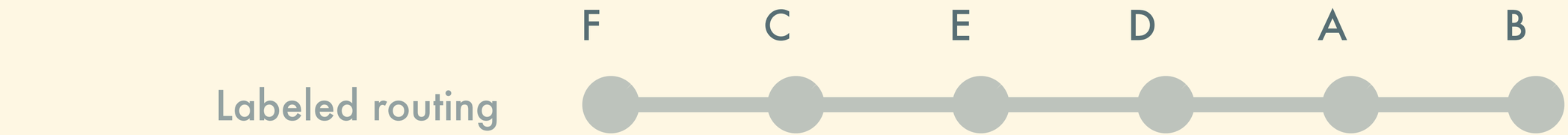
Query route to « A »

Name-independent vs. Labeled

The short answer

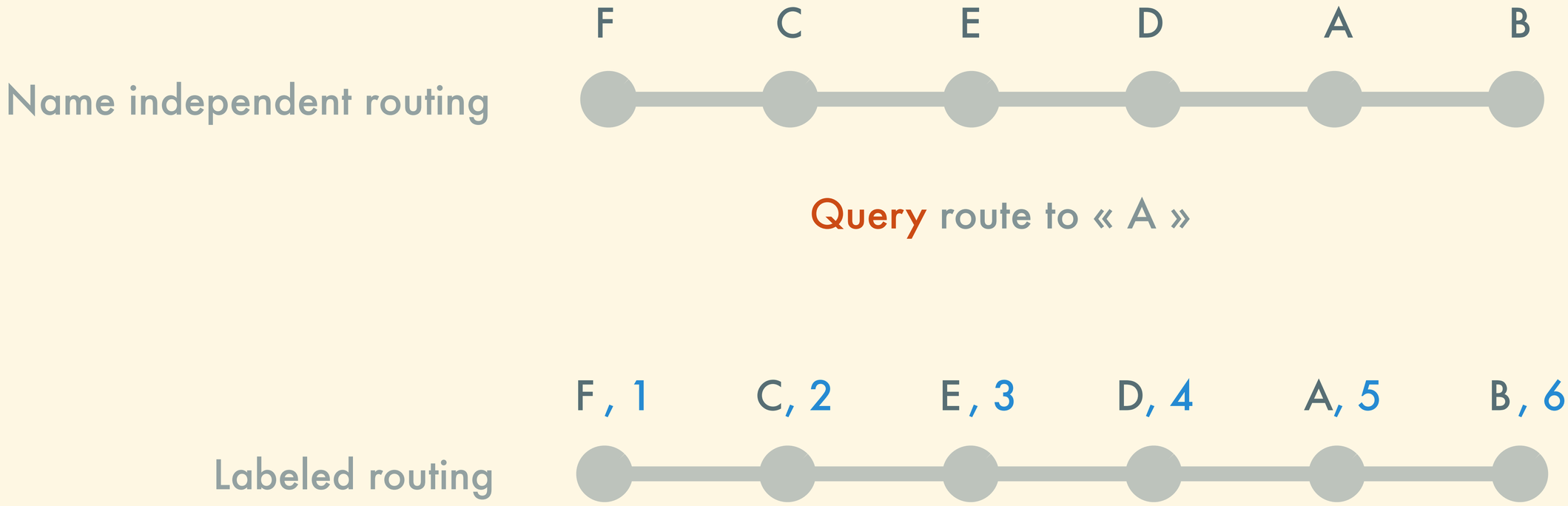


Query route to « A »



Name-independent vs. Labeled

The short answer



Name-independent vs. Labeled

The short answer

Name independent routing

Query route to « A »

Labeled routing

Query route to « A, 5 »

Tradeoffs (Name-independent)

lower bounds

	Stretch	Memory	Communication cost
[AGM'06a]	$< 2k+1$	$\Omega(n^{1/k})$	any

TRADEOFFS (NAME-INDEPENDENT)

lower bounds

	Stretch	Memory	Communication cost
[AGM'06a]	$< 2k+1$	$\Omega(n^{1/k})$	any
[GGHI'13]	1	any	$\Omega(n^2)$

TRADEOFFS (NAME-INDEPENDENT)

lower bounds

upper bounds

	Stretch	Memory	Communication cost
[AGM'06a]	$< 2k+1$	$\Omega(n^{1/k})$	any
[GGHI'13]	1	any	$\Omega(n^2)$
BFS-tree	1	$\tilde{O}(n)$	$\tilde{O}(nm)$

TRADEOFFS (NAME-INDEPENDENT)

	Stretch	Memory	Communication cost
lower bounds			
[AGM'06a]	$< 2k+1$ < 3	$\Omega(n^{1/k})$ $\Omega(n)$	any
[GGHI'13]	1	any	$\Omega(n^2)$
upper bounds			
BFS-tree	1 optimal	$\tilde{O}(n)$	$\tilde{O}(nm)$

TRADEOFFS (NAME-INDEPENDENT)

	Stretch	Memory	Communication cost
lower bounds			
[AGM'06a]	$< 2k+1$ < 3	$\Omega(n^{1/k})$ $\Omega(n)$	any
[GGHI'13]	1	any	$\Omega(n^2)$
upper bounds			
BFS-tree	1 optimal	$\tilde{O}(n)$	$\tilde{O}(nm)$
[AR'93]	1	$\tilde{O}(n)$	$\tilde{O}(n^2)$

Tradeoffs (Name-independent)

	Stretch	Memory	Communication cost
lower bounds			
[AGM'06a]	$< 2k+1$ < 3	$\Omega(n^{1/k})$ $\Omega(n)$	any
[GGHI'13]	1	any	$\Omega(n^2)$
upper bounds			
BFS-tree	1 optimal	$\tilde{O}(n)$	$\tilde{O}(nm)$
[AR'93]	1	$\tilde{O}(n)$	$\tilde{O}(n^2)$
[AGM'06b]	$O(k)$	$\tilde{O}(n^{1/k})$	centralised

Tradeoffs (Name-independent)

		Stretch	Memory	Communication cost
lower bounds	[AGM'06a]	$< 2k+1$ < 3	$\Omega(n^{1/k})$ $\Omega(n)$	any
	[GGHI'13]	1	any	$\Omega(n^2)$
upper bounds	BFS-tree	1 optimal	$\tilde{O}(n)$	$\tilde{O}(nm)$
	[AR'93]	1	$\tilde{O}(n)$	$\tilde{O}(n^2)$
	[AGM'06b]	$O(k)$	$\tilde{O}(n^{1/k})$	centralised
	[AGM'08]	3	$\tilde{O}(\sqrt{n})$	centralised

Tradeoffs (Name-independent)

	Stretch	Memory	Communication cost
lower bounds			
[AGM'06a]	$< 2k+1$; < 3 ; < 5	$\Omega(n^{1/k})$; $\Omega(n)$; $\Omega(\sqrt{n})$	any
[GGHI'13]	1	any	$\Omega(n^2)$
upper bounds			
BFS-tree	1 optimal	$\tilde{O}(n)$	$\tilde{O}(nm)$
[AR'93]	1	$\tilde{O}(n)$	$\tilde{O}(n^2)$
[AGM'06b]	$O(k)$	$\tilde{O}(n^{1/k})$	centralised
[AGM'08]	3 optimal	$\tilde{O}(\sqrt{n})$	centralised

Tradeoffs (Name-independent)

	Stretch	Memory	Communication cost
lower bounds	[AGM'06a]	$< 2k+1$ (< 3, < 5)	$\Omega(n^{1/k})$ ($\Omega(n)$, $\Omega(\sqrt{n})$)	any
	[GGHI'13]	1	any	$\Omega(n^2)$
upper bounds	BFS-tree	1	$\tilde{O}(n)$	$\tilde{O}(nm)$
	[AR'93]	1 (optimal)	$\tilde{O}(n)$	$\tilde{O}(n^2)$
	[AGM'06b]	$O(k)$	$\tilde{O}(n^{1/k})$	centralised
	[AGM'08]	3 (optimal)	$\tilde{O}(\sqrt{n})$	centralised
	[SGF+10]	7	$\tilde{O}(\sqrt{n})$	NC.

Tradeoffs (Name-independent)

		Stretch		Memory		Communication cost
lower bounds	[AGM'06a]	$< 2k+1$	< 3 < 5	$\Omega(n^{1/k})$	$\Omega(n)$ $\Omega(\sqrt{n})$	any
	[GGHI'13]	1		any		$\Omega(n^2)$
upper bounds	BFS-tree	1	optimal	$\tilde{O}(n)$		$\tilde{O}(nm)$
	[AR'93]	1		$\tilde{O}(n)$		$\tilde{O}(n^2)$
	[AGM'06b]	$O(k)$		$\tilde{O}(n^{1/k})$		centralised
	[AGM'08]	3	optimal	$\tilde{O}(\sqrt{n})$		centralised
	[SGF+10]	7		$\tilde{O}(\sqrt{n})$		NC.
	[GGHI'13]	7		$\tilde{O}(\sqrt{n})$		$O(m\sqrt{n})$

Tradeoffs (Name-independent)

		Stretch		Memory		Communication cost
lower bounds	[AGM'06a]	$< 2k+1$	< 3 < 5	$\Omega(n^{1/k})$	$\Omega(n)$ $\Omega(\sqrt{n})$	any
	[GGHI'13]	1		any		$\Omega(n^2)$
upper bounds	BFS-tree	1	optimal	$\tilde{O}(n)$		$\tilde{O}(nm)$
	[AR'93]	1		$\tilde{O}(n)$		$\tilde{O}(n^2)$
	[AGM'06b]	$O(k)$		$\tilde{O}(n^{1/k})$		centralised
	[AGM'08]	3	optimal	$\tilde{O}(\sqrt{n})$		centralised
	[SGF+10]	7		$\tilde{O}(\sqrt{n})$		NC.
	[GGHI'13]	7		$\tilde{O}(\sqrt{n})$		$O(m\sqrt{n})$
	my thesis	5		$\tilde{O}(\sqrt{n})$		$O(m\sqrt{n})$

TRADEOFFS (LABELED)

lower bounds

upper bounds

	Stretch	Memory	Communication cost
[AGM'06]	$< 2k+1$	$\Omega(n^{1/k})$	any

TRADEOFFS (LABELED)

lower bounds

upper bounds

	Stretch	Memory	Communication cost
[AGM'06]	$< 2k+1$	$\Omega(n^{1/k})$	any
[GGHI'13]	1	any	$\Omega(n^2)$

TRADEOFFS (LABELED)

lower bounds

upper bounds

	Stretch	Memory	Communication cost
[AGM'06]	$< 2k+1$	$\Omega(n^{1/k})$	any
[GGHI'13]	1	any	$\Omega(n^2)$
All name-independent results hold,			

TRADEOFFS (LABELED)

	Stretch	Memory	Communication cost
lower bounds			
[AGM'06]	$< 2k+1$	$\Omega(n^{1/k})$	any
[GGHI'13]	1	any	$\Omega(n^2)$
All name-independent results hold,			
upper bounds			
[TZ'01]	$4k-5$	$\tilde{O}(n^{1/k})$	centralised

TRADEOFFS (LABELED)

	Stretch	Memory	Communication cost
lower bounds			
[AGM'06]	$< 2k+1$	$\Omega(n^{1/k})$	any
[GGHI'13]	1	any	$\Omega(n^2)$
All name-independent results hold,			
upper bounds			
[TZ'01]	$4k-5$	$\tilde{O}(n^{1/k})$	centralised
[TZ'01]	3	$\tilde{O}(\sqrt{n})$	centralised

HOW TO BUILD A ROUTING SCHEME

PART I : Labeled Compact Routing in Trees

Labeled compact routing in trees

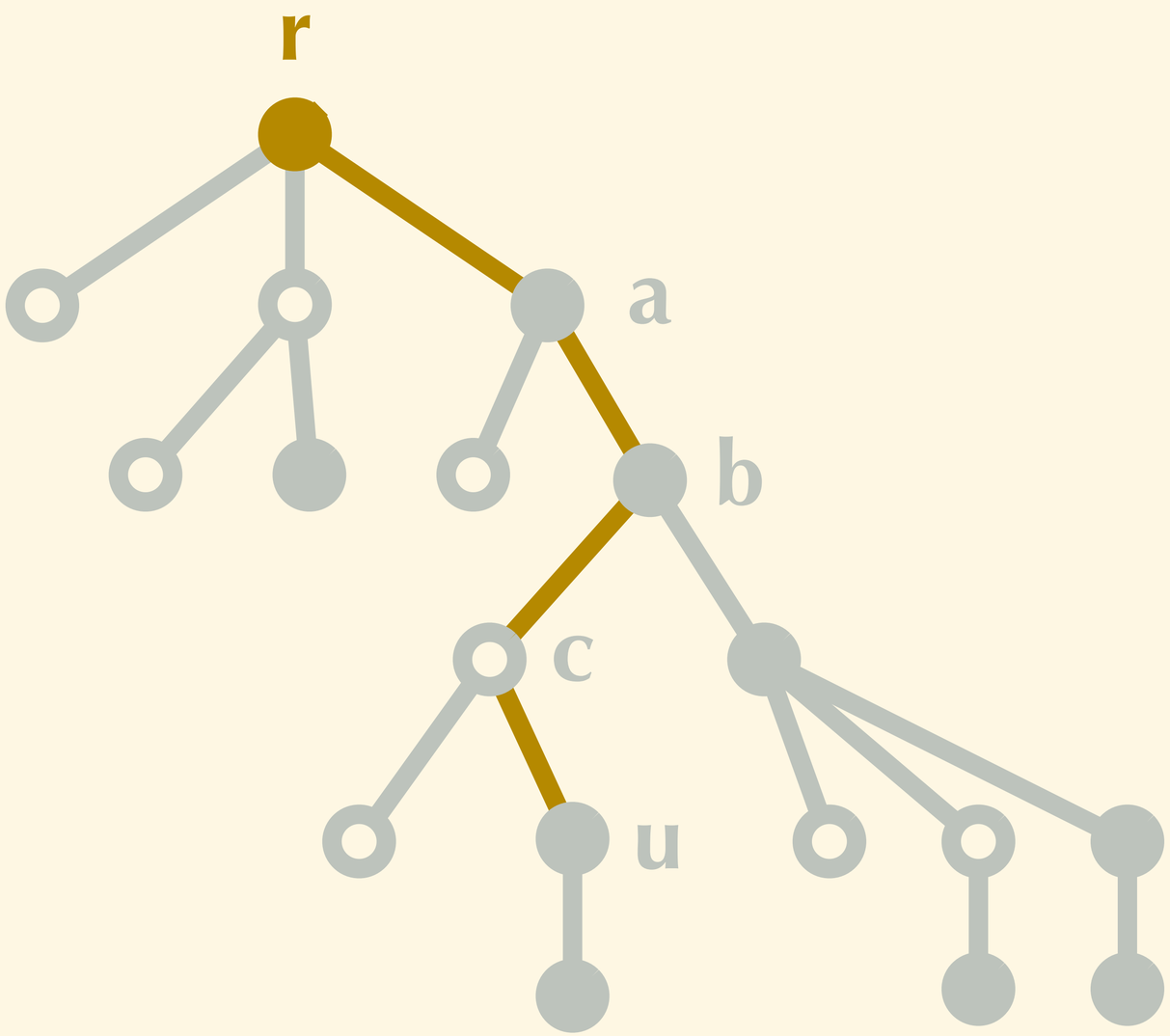
Two candidates

- I will not talk about the difference, they have very similar performances:
  - "Thorup-Zwick" [TZ'01]
  - "Fraigniaud-Gavoille" [FG'01]
- Achieve labeled compact routing in rooted trees with:
  - Memory space: $O(\log^2 n)$*
  - Stretch: 1
  - (Constant query time)

*[FG'01] actually have a $O(\log^2 n/\text{loglog } n)$ memory space

LABELED COMPACT ROUTING IN TREES

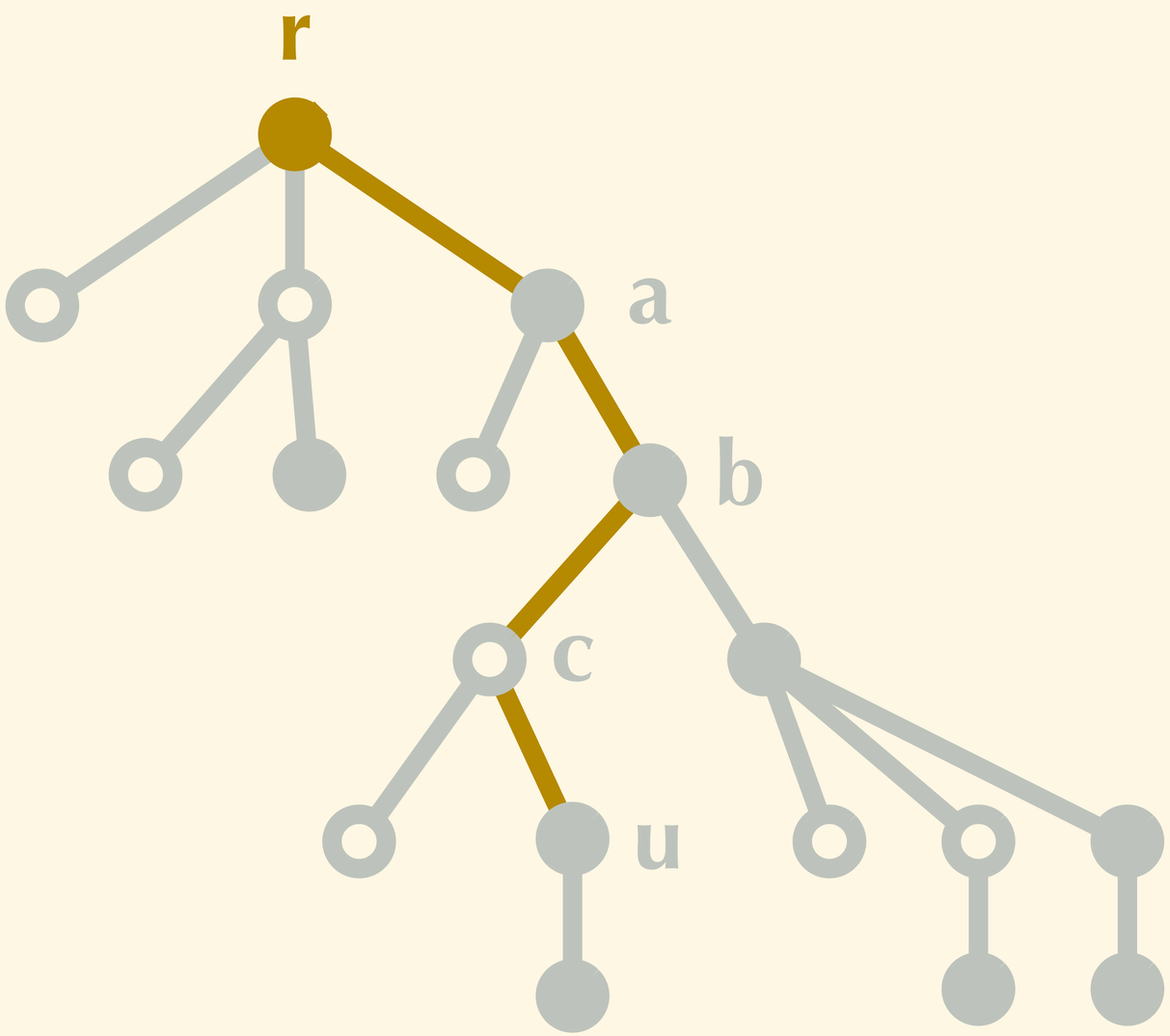
Fraignaud-Gavoille - Heavy child



- GOAL, for every node u:
  - compute the compact routing label $\ell(u)$ which represent path from u to r in the tree.
- First step, heavy children nodes:
  - in the example the heavy child is always the rightmost one.

Labeled compact routing in trees

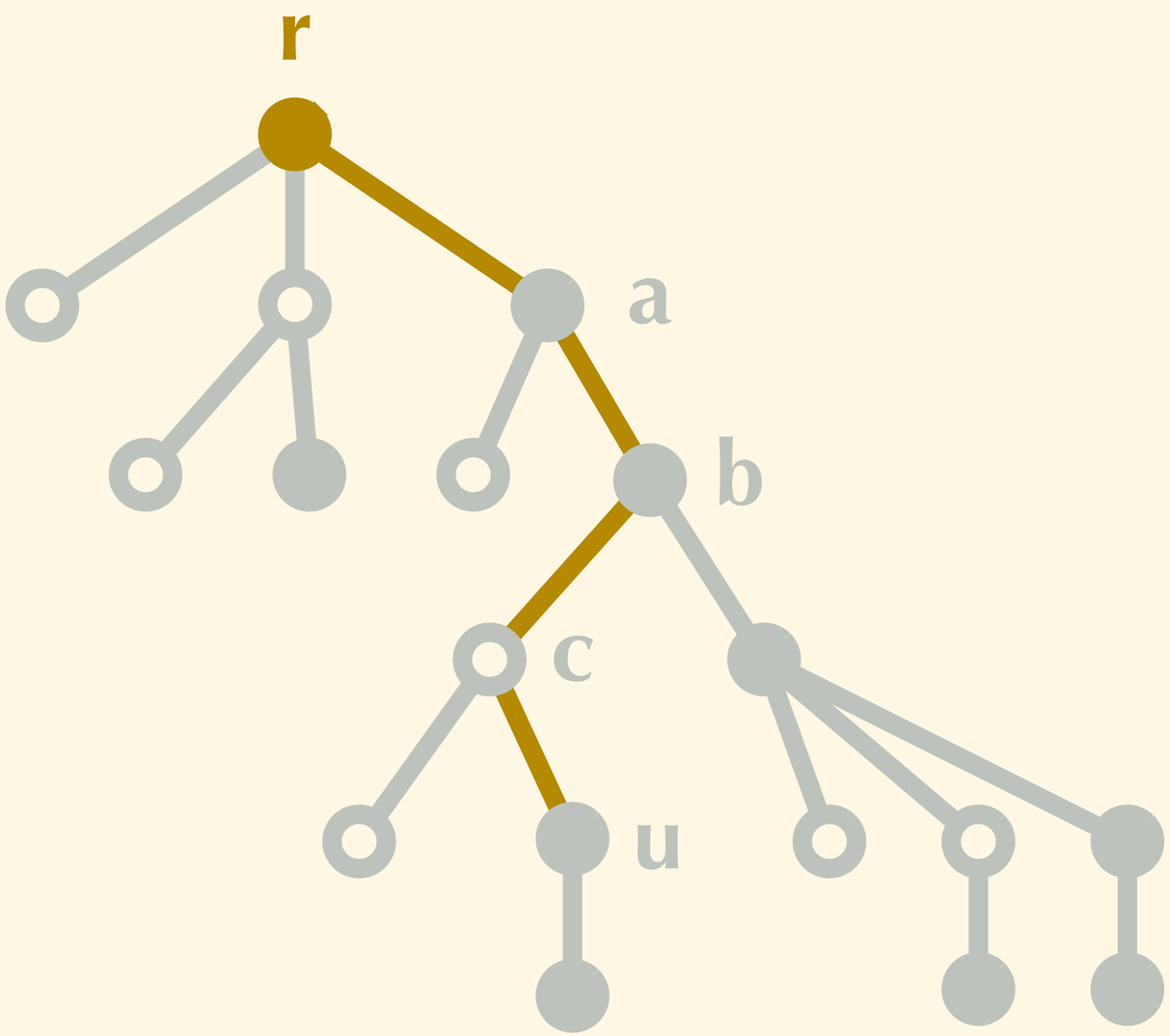
Fraignaud-Gavoille - Nodes names



path	r	a	b	c	u

Labeled compact routing in trees

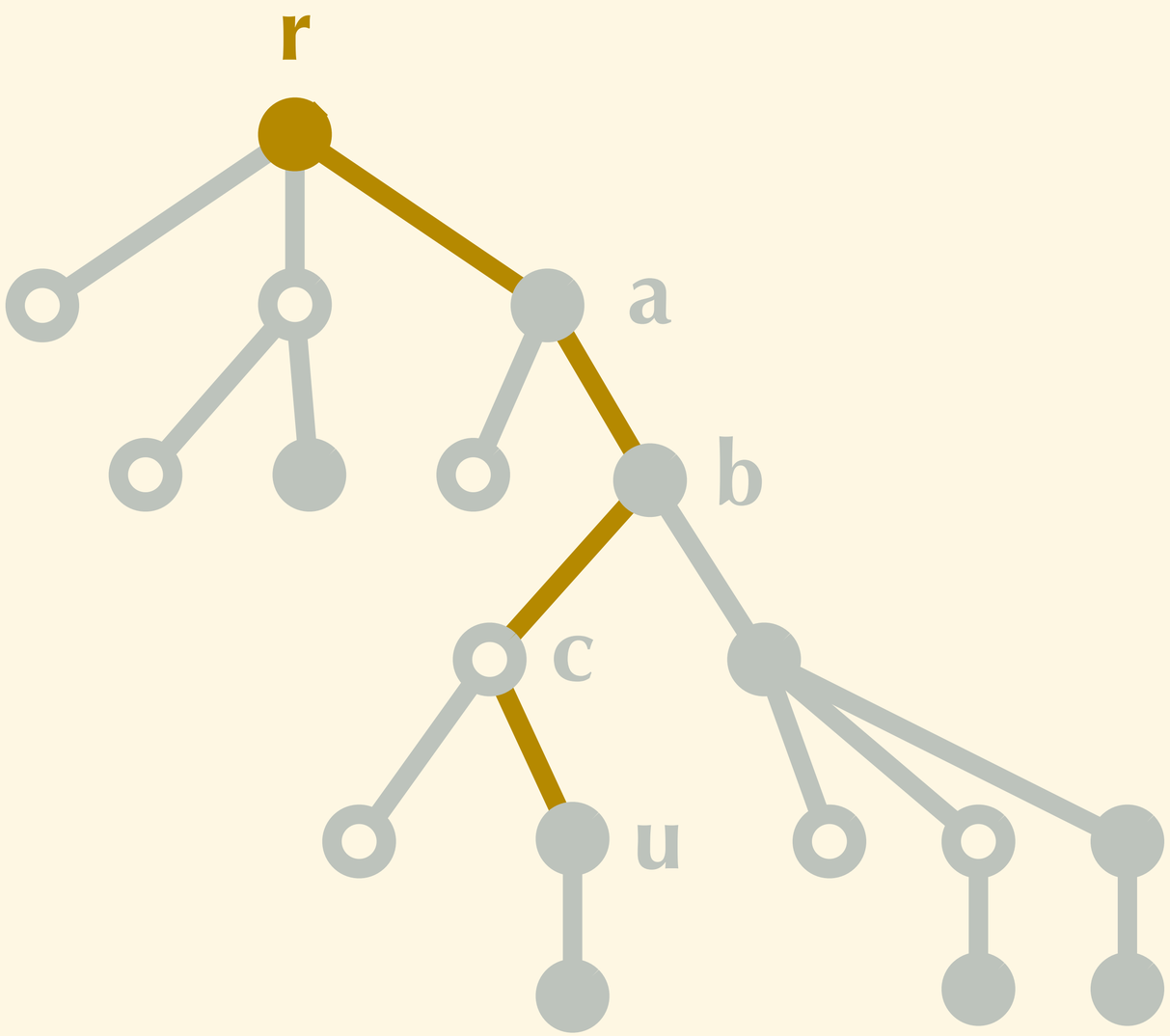
Fraignaud-Gavoille - Nodes names



path	r	a	b	c	u
path*	r	*	*	c	*

Labeled compact routing in trees

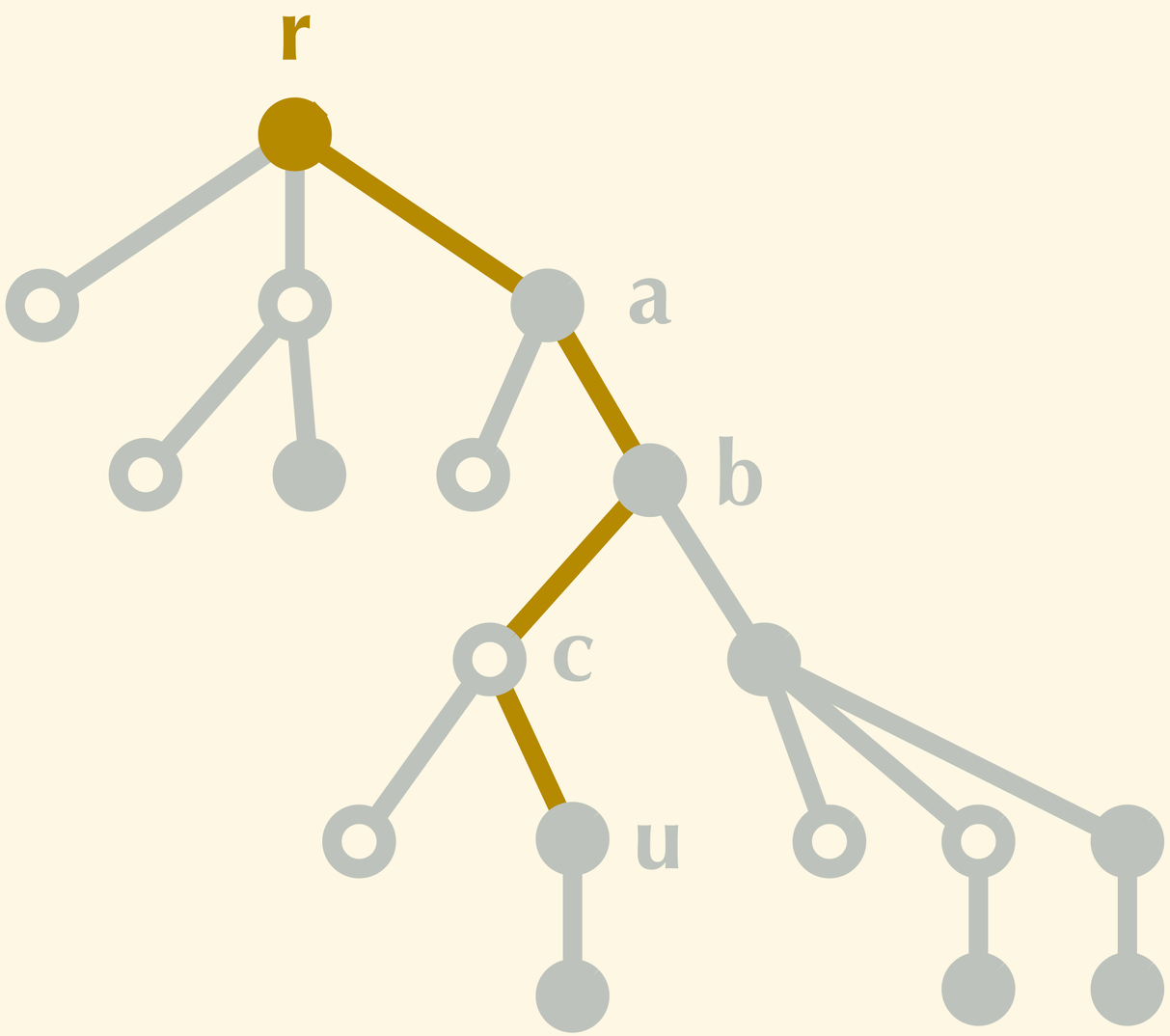
Fraignaud-Gavoille - Nodes names



path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r		2	c	1

Labeled compact routing in trees

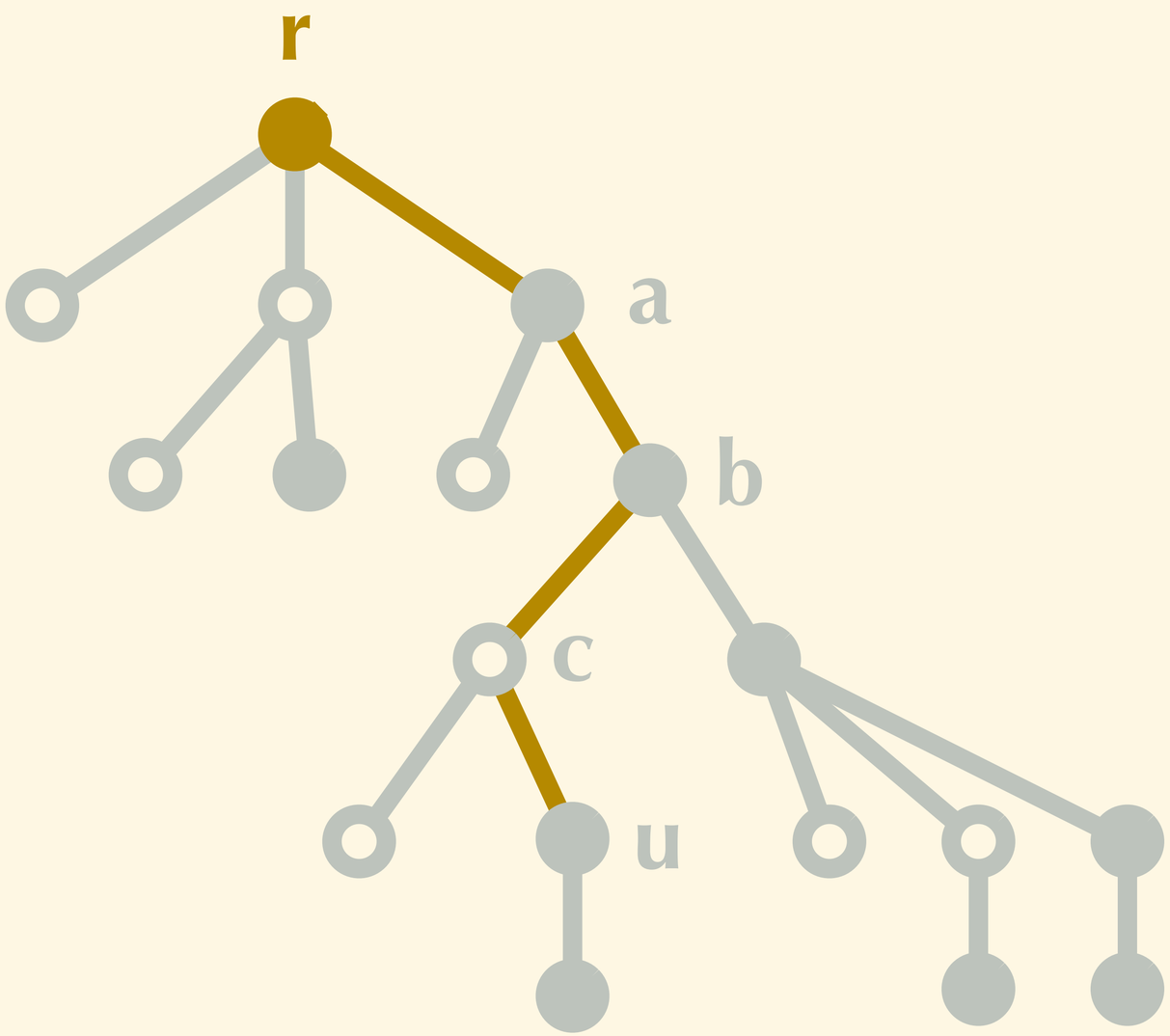
Fraignaud-Gavoille - Nodes names



path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r		2	c	1
b_u	1		0	1	0

Labeled compact routing in trees

Fraignaud-Gavoille - Nodes names



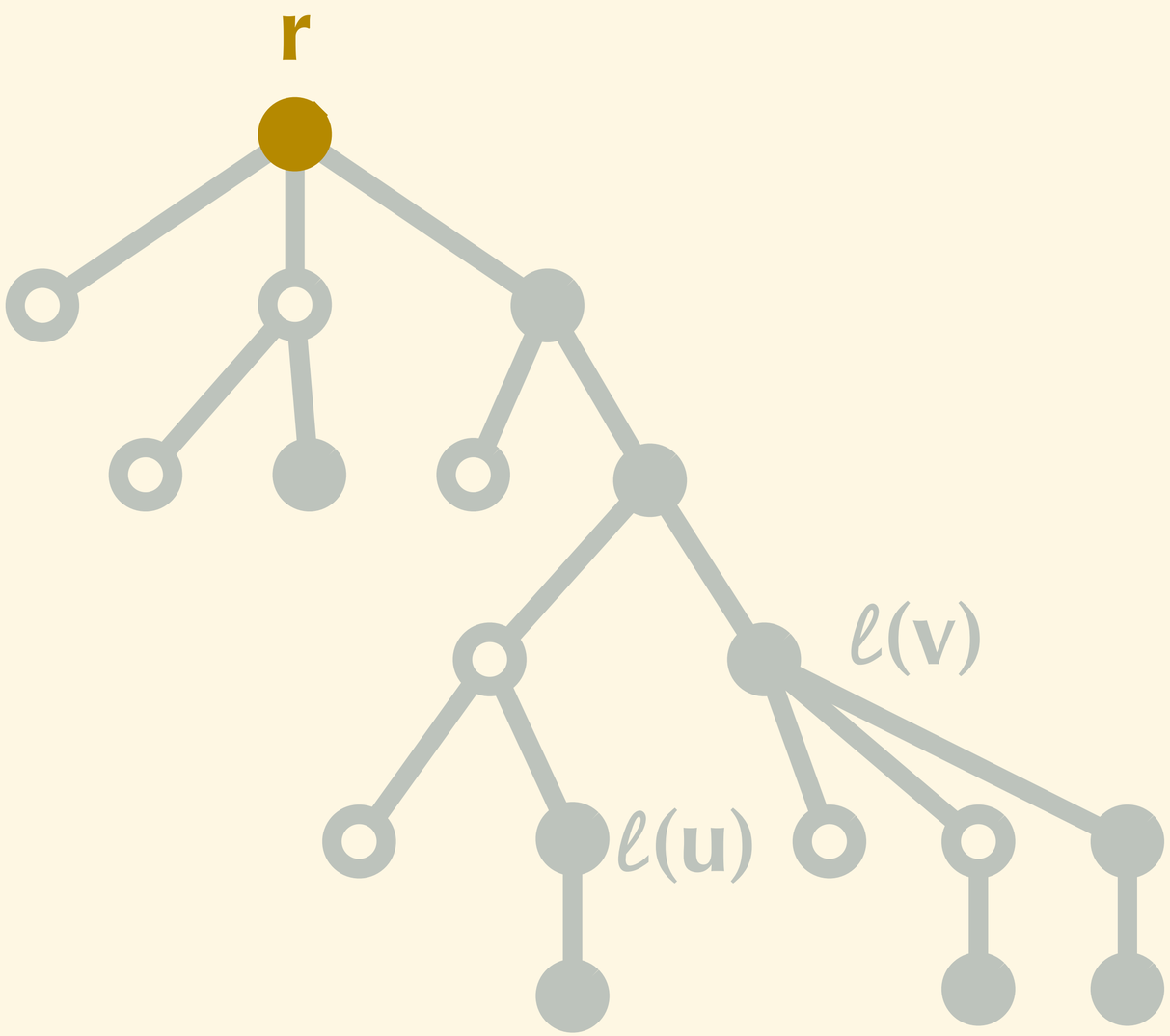
path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r		2	c	1
b_u	1		0	1	0

Finally we set the name of node u to

$\ell(u) = (u, cpath\_u, b\_u)$

LABELED COMPACT ROUTING IN TREES

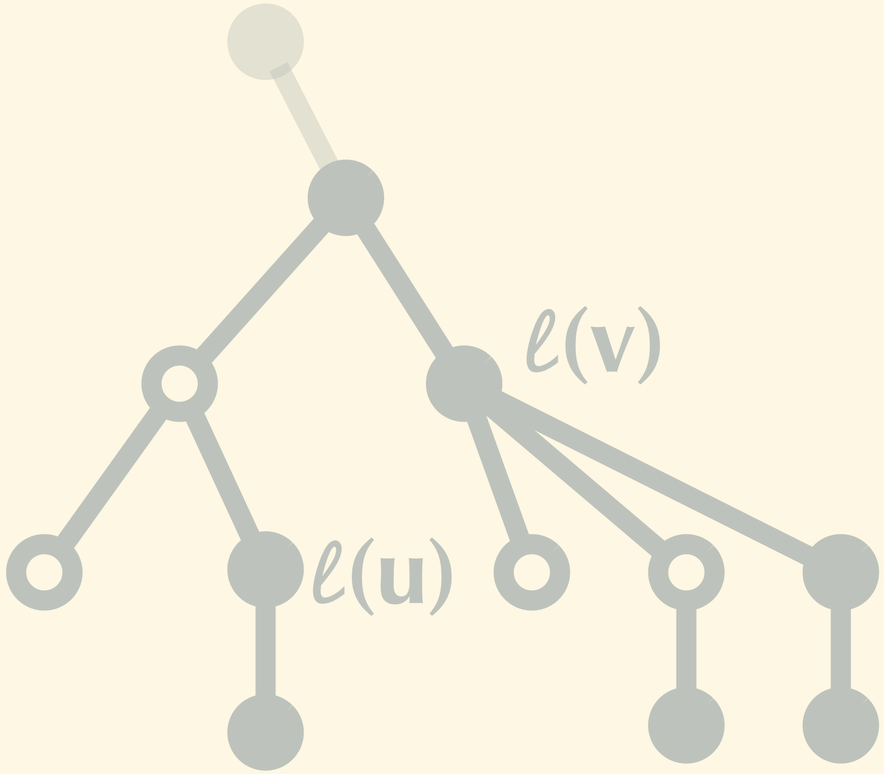
Fraignaud-Gavoille - Routing tables



- Routing tables are very small, every node stores two entries:
  - link to the parent
  - link to the heavy child
- Routing is based on "prefix comparisons" of the source and destination labels.

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Routing algorithm (roughly)



$\ell(u)$

cpath_u	r	2	c	1
b_u	1	0	1	0

$\ell(v)$

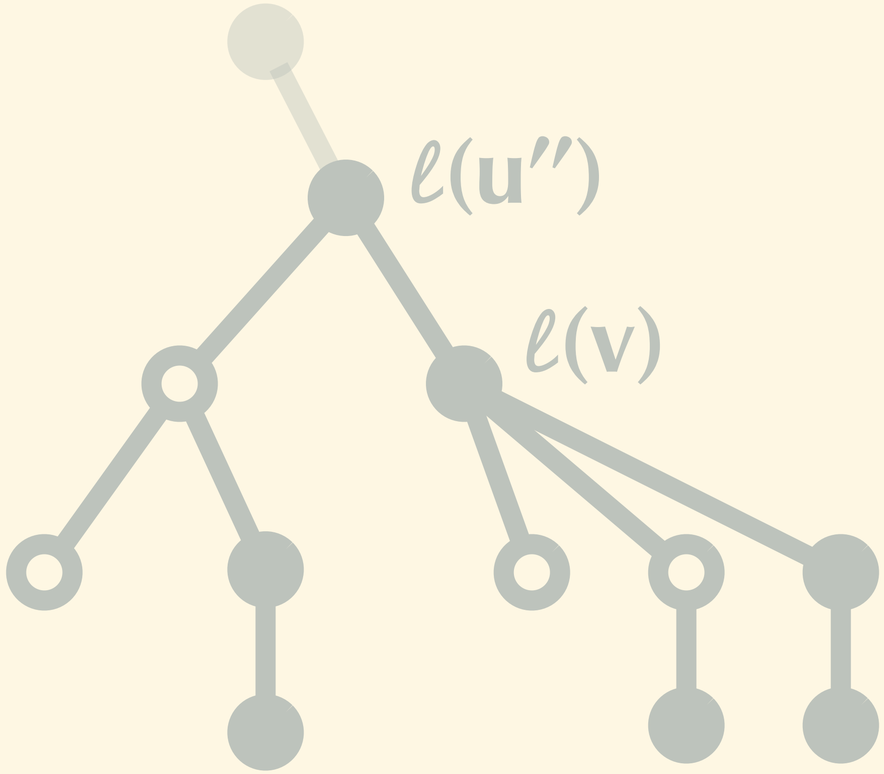
cpath_v	r	3
b_v	1	0

Routing:

- b_u **is not a prefix of** b_v ⇒ $\ell(v)$ **is not a descendent**
- **route toward parent of** $\ell(u)$ **(info. in routing table)**

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Routing algorithm (roughly)



ℓ(u″)

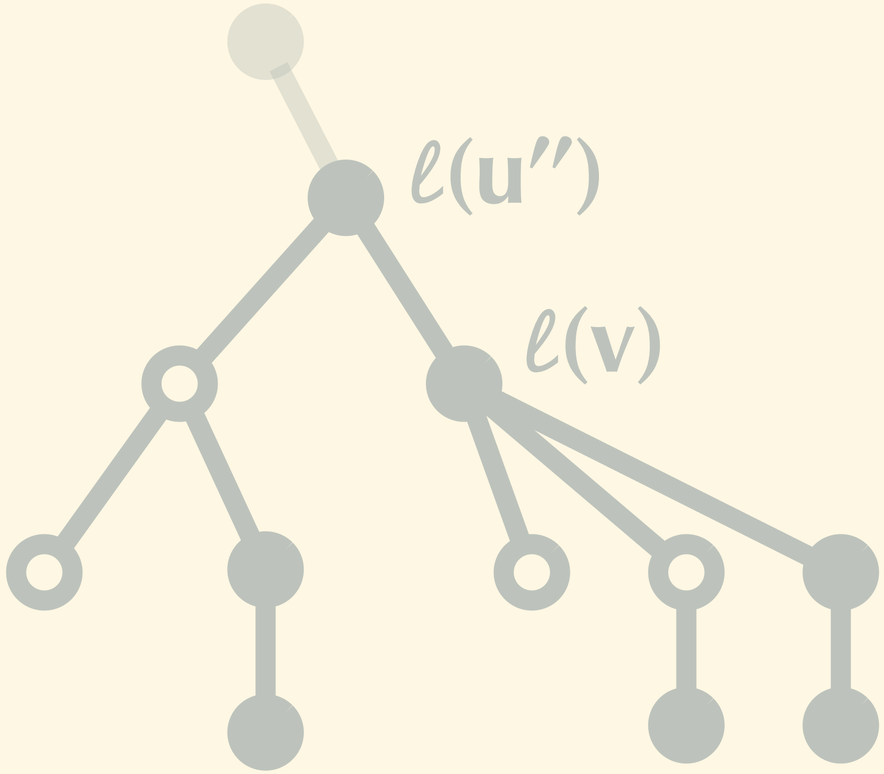
cpath_u″	r	2
b_u″	1	0

ℓ(v)

cpath_v	r	3
b_v	1	0

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Routing algorithm (roughly)



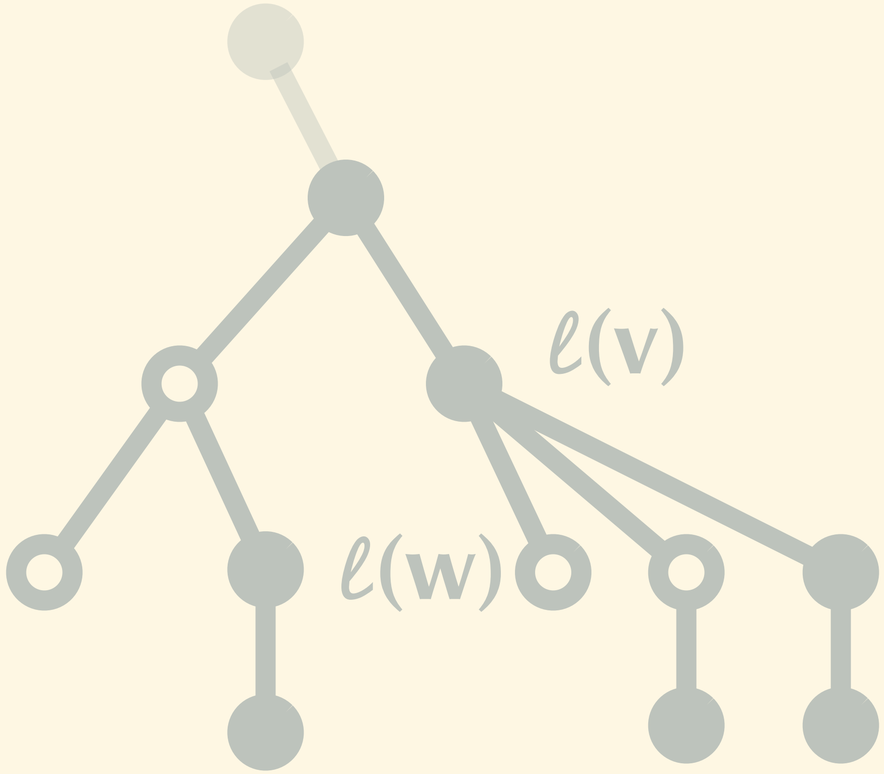
ℓ(u'')	cpath_u''	r	2
	b_u''	1	0
ℓ(v)	cpath_v	r	3
	b_v	1	0

Routing:

- $\ell(u'')$ **is almost a prefix of** $\ell(v)$
- cpath_u''[-1] < cpath_v[-1]
  therefore $\ell(v)$ **is a descendent of** $\ell(u'')$
- **since** b_v **ends with 0,** $\ell(v)$ **is in the heavy side,**
- **route using the routing table of** $\ell(u'')$

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Routing algorithm (roughly)



ℓ(v)

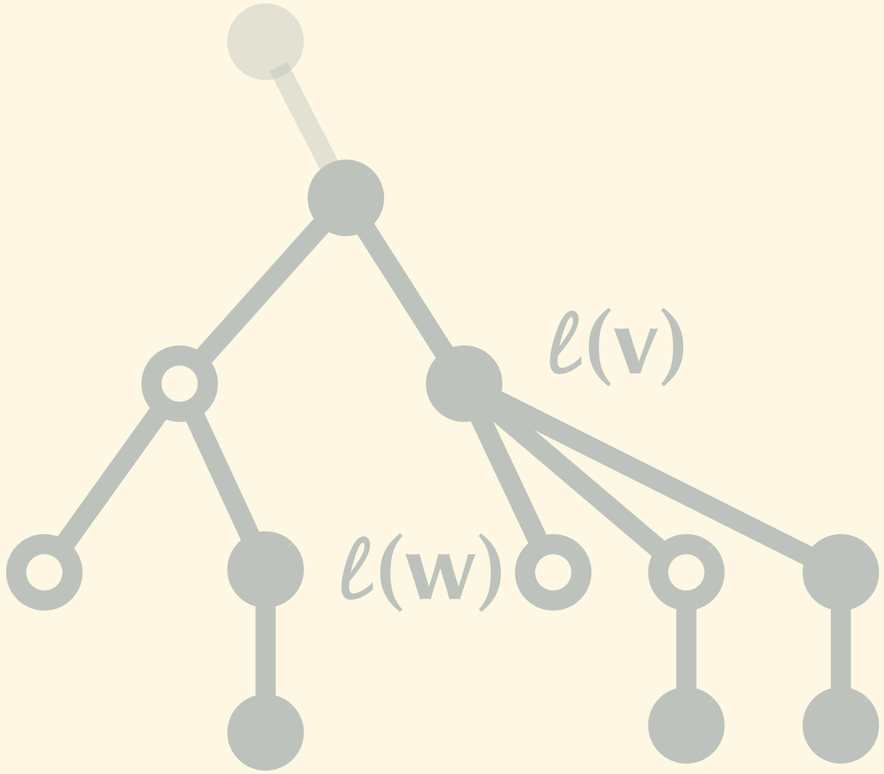
cpath_w	r	3
b_w	1	0

ℓ(w)

cpath_v	r	3	w
b_v	1	0	1

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Routing algorithm (roughly)



$\ell(v)$

cpath_w	r	3	
b_w	1	0	

$\ell(w)$

cpath_v	r	3	w
b_v	1	0	1

Routing:

- similarly as before, but in this case the routing information is retrieved in the cpath of $\ell(v)$.

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Labels size

- Now we know that routing can be achieved giving nodes labels, with two routing entries per node.
- But what about the nodes names (labels) sizes?

Labeled compact routing in trees

Fraignaud-Gavoille - Labels size

path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r		2	c	1
b_u	1		0	1	0

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Labels size

path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r		2	c	1
b_u	1		0	1	0

- Size of path can be n.
- What about cpath size?

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Labels size

path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r	2		c	1
b_u	1	0		1	0

- Size of path can be n.
- What about cpath size?
  - What is the maximum number of 1's in b_u? #of non-heavy children? (clue: the worst-case-tree is the binary one, why?)

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Labels size

path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r	2		c	1
b_u	1	0		1	0

- Size of path can be n.
- What about cpath size?
  - What is the maximum number of 1's in b_u? #of non-heavy children? (clue: the worst-case-tree is the binary one, why?)
  - By definition, path* stars are grouped if they are consecutive, therefore the number of 0's in b_u is also bounded by log n.

LABELED COMPACT ROUTING IN TREES

Fraignaud-Gavoille - Labels size

path	r	a	b	c	u
path*	r	*	*	c	*
cpath_u	r	2		c	1
b_u	1	0		1	0

- Size of path can be n.
- What about cpath size?
  - What is the maximum number of 1's in b_u? #of non-heavy children? (clue: the worst-case-tree is the binary one, why?)
  - By definition, path* stars are grouped if they are consecutive, therefore the number of 0's in b_u is also bounded by log n.
- Every item in cpath is of size O(log n) (either a length or a node id), therefore, the total size of $\ell(u)$ is $O(\log^2 n)$.

Labeled compact routing in trees

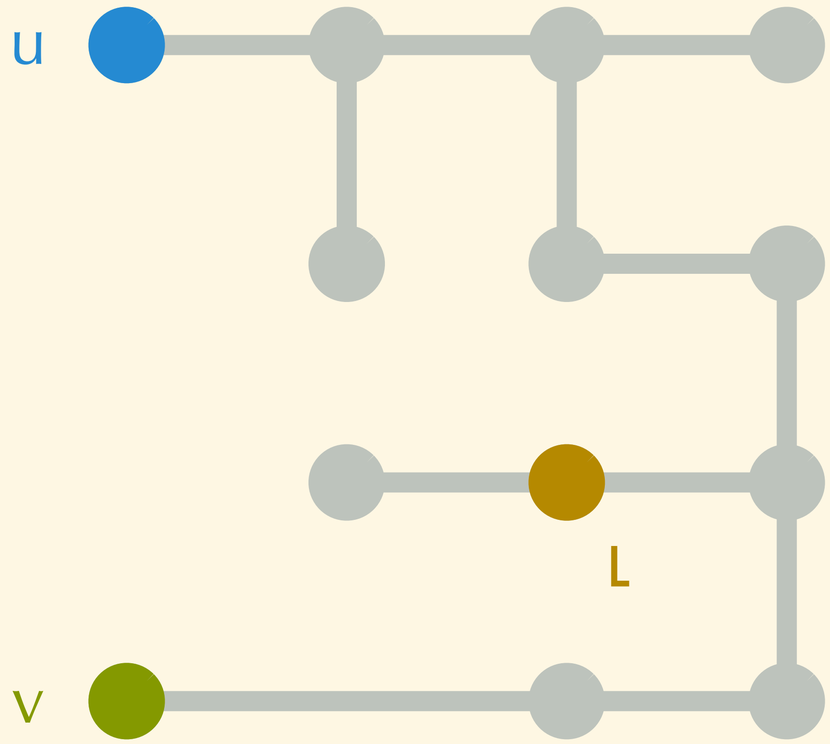
Two candidates

- Performances of [FG'01] for rooted trees:
  - Memory space: $O(\log^2 n)$
  - Stretch: 1 (shortest path)
  - Labeled scheme

HOW TO BUILD A ROUTING SCHEME

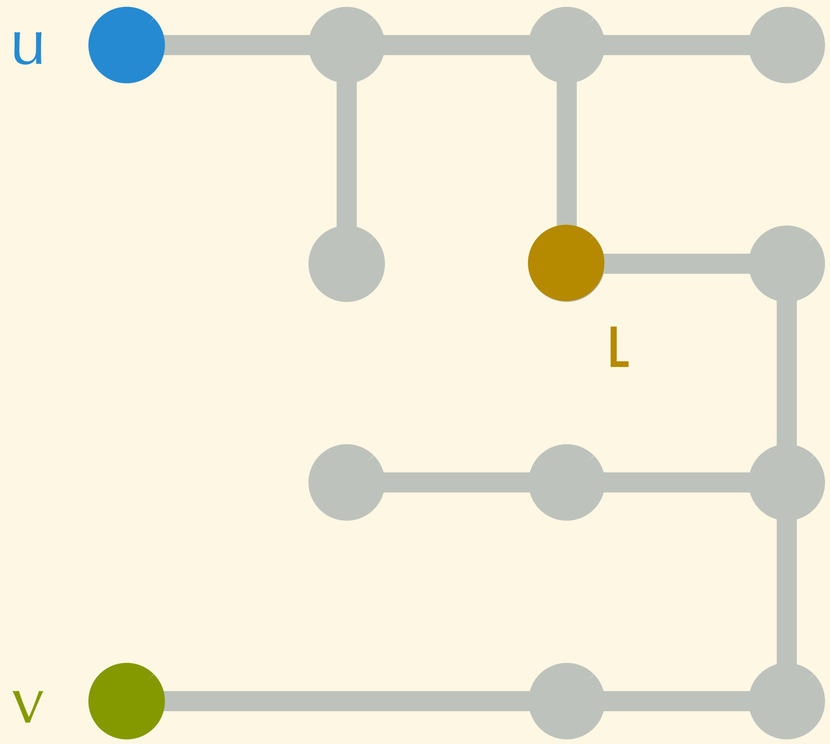
PART II : Labeled compact routing for general graphs

USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



- Using "reference node(s)"
  - we call them, Landmark(s)

USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



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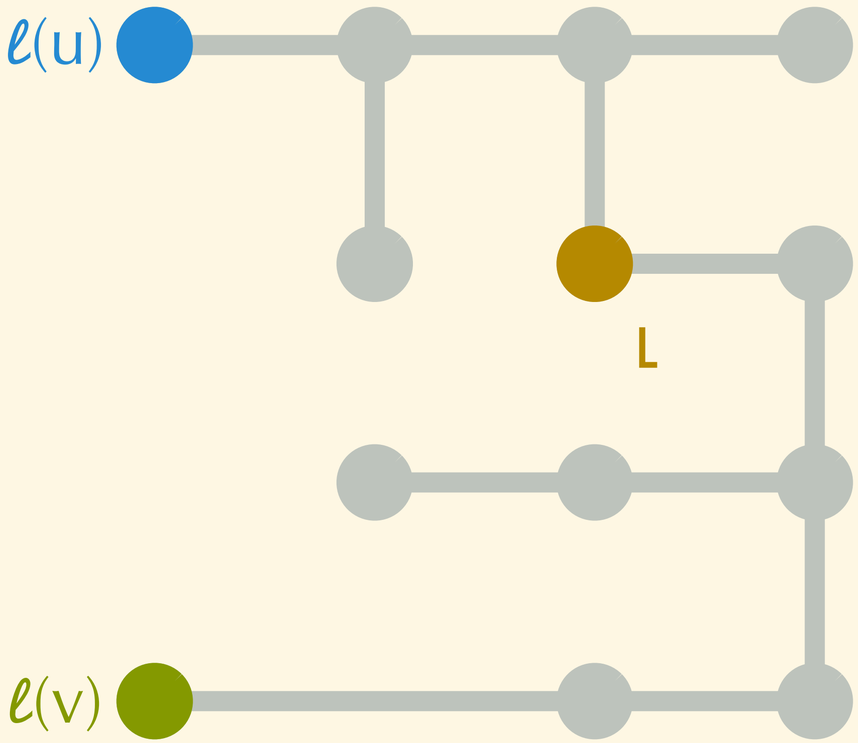
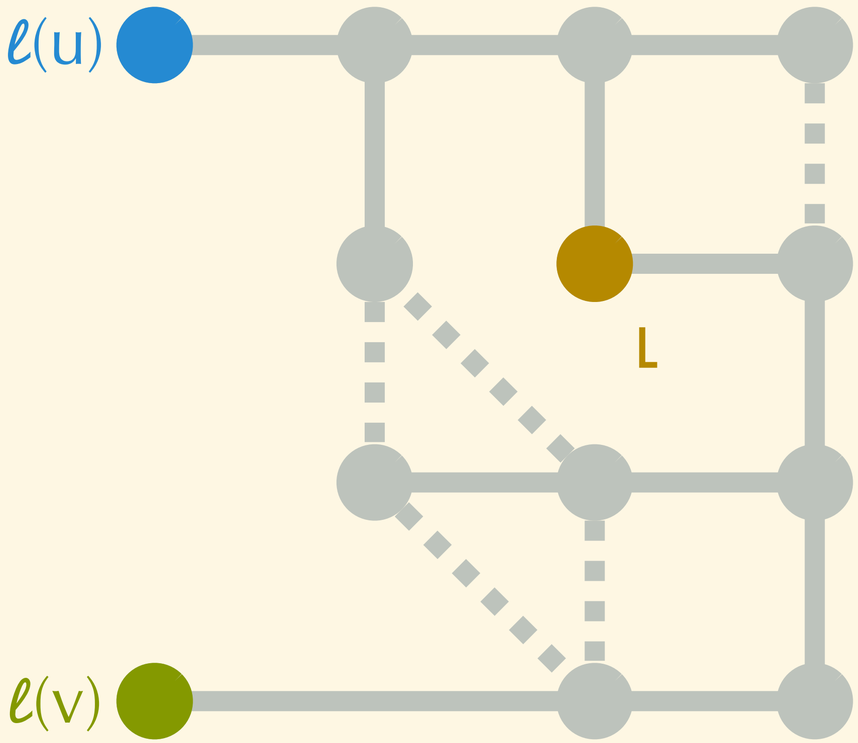


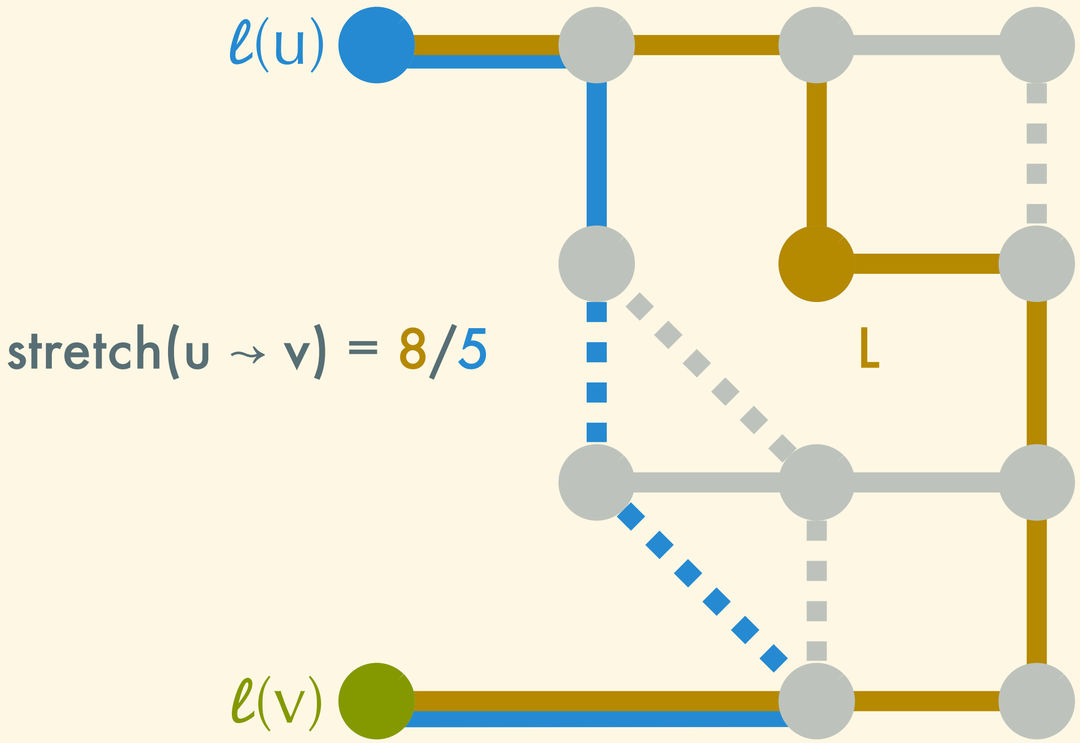
- In a tree, with [FG'01], we can do shortest path with constant memory in the labeled model.

USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



- In a tree, with [FG'01], we can do shortest path with constant memory in the labeled model.
- But not every graph is a tree …

USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



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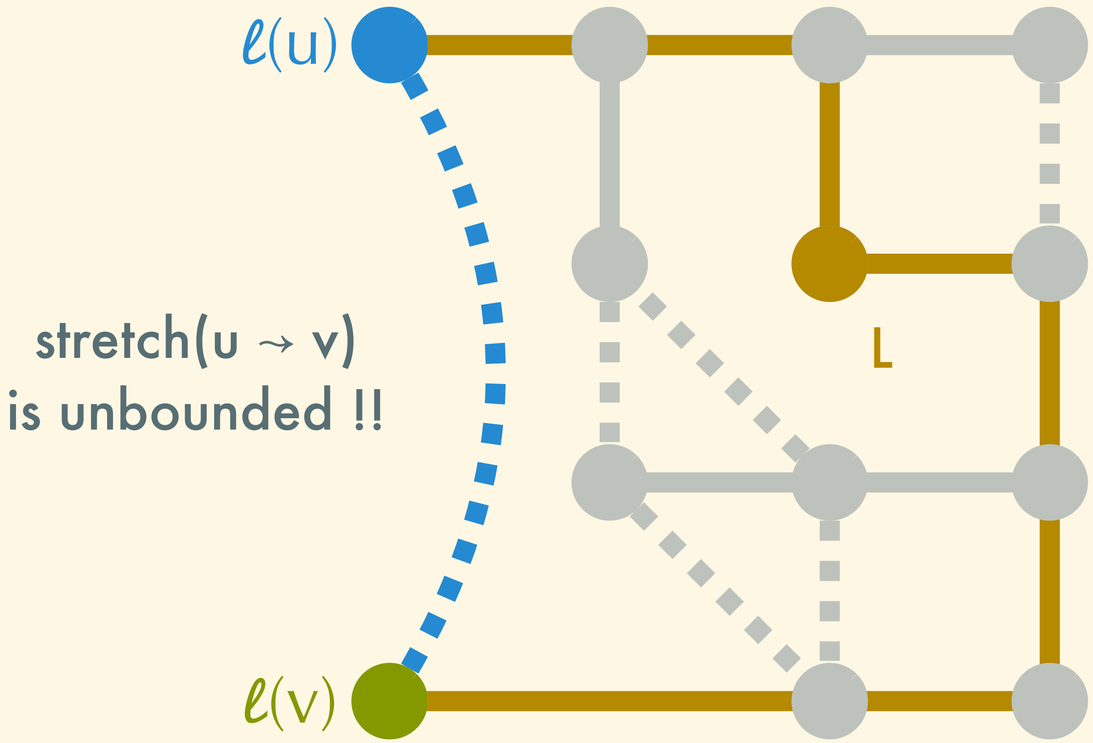
USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



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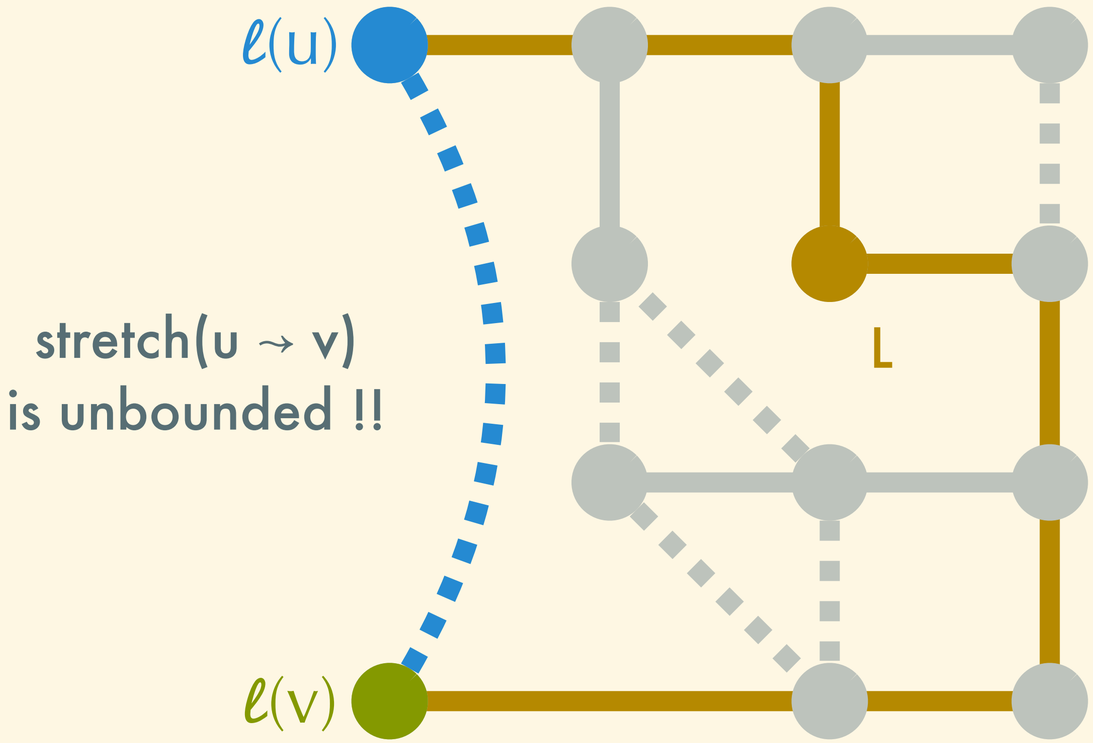
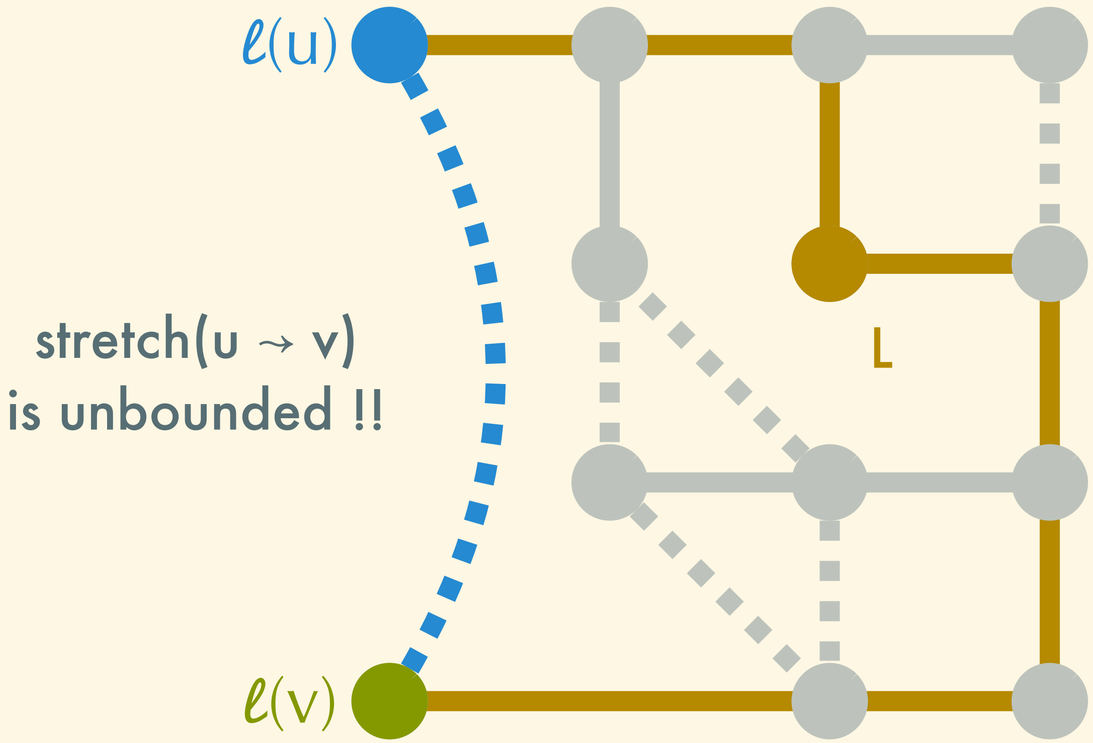
USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



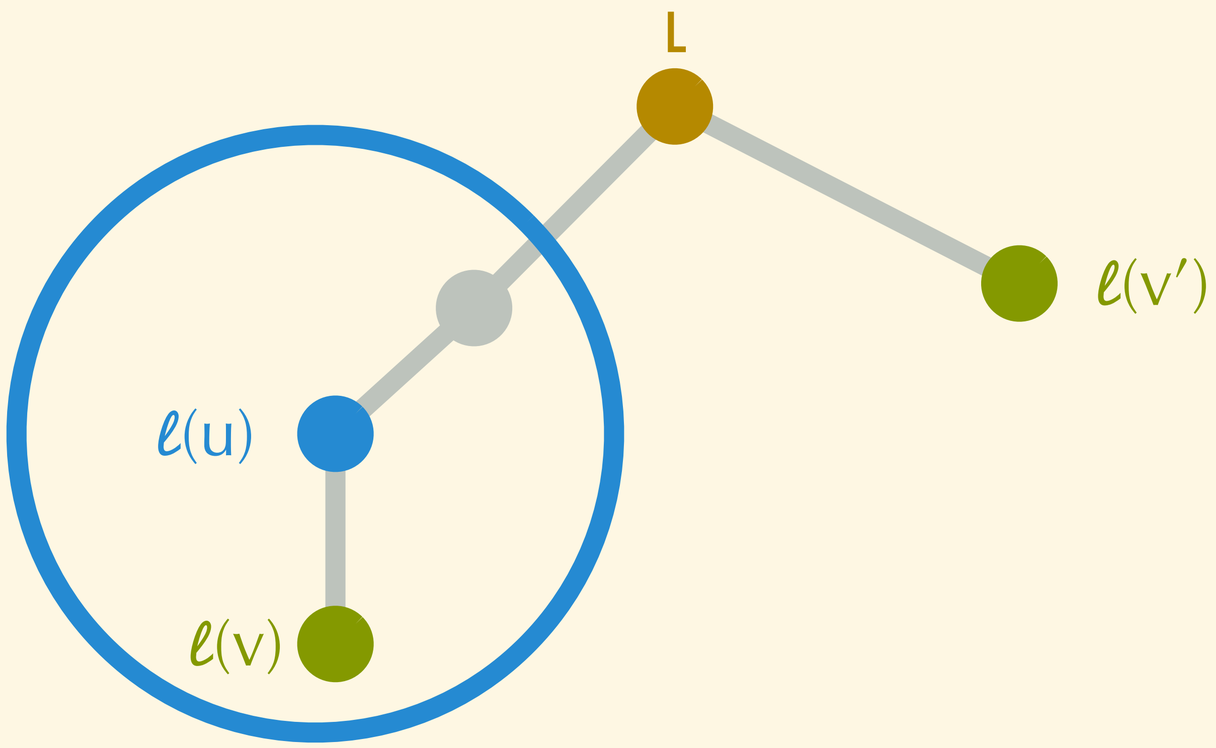
- In a tree, with [FG'01], we can do shortest path with constant memory in the labeled model.
- But not every graph is a tree …
- The stretch can be unbounded.

USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



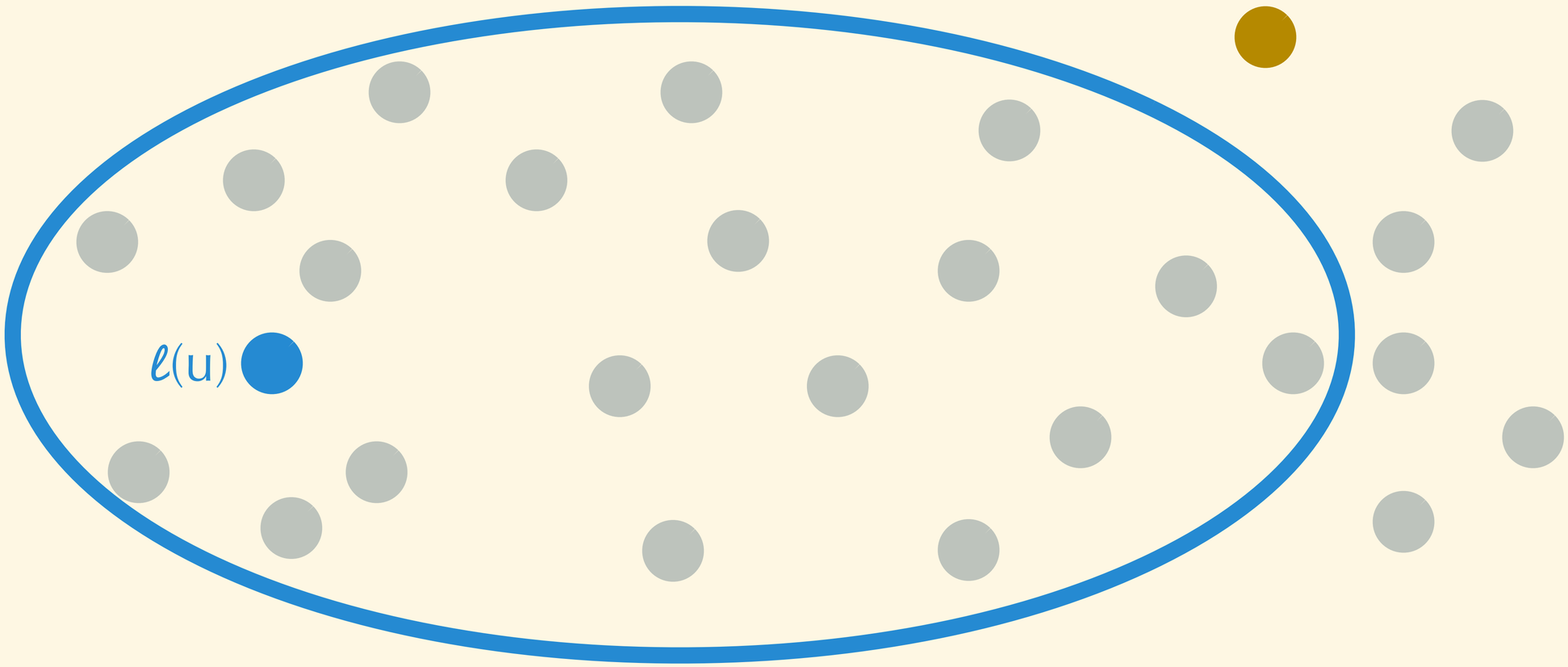
- In a tree, with [FG'01], we can do shortest path with constant memory in the labeled model.
- But not every graph is a tree …
- The stretch can be unbounded.
- Solution: use *"vicinity balls"*

USING [FG'01] TO DESIGN UNIVERSAL COMPACT ROUTING SCHEMES



- For nodes closer than L e.g., ℓ(v), use classical shortest path routing
- For others e.g., ℓ(v'), use [FG'01] routing
- This way the stretch is bounded by 3.
- But … vicinity balls can be huge, and so as the routing tables size.

Labeled compact routing scheme



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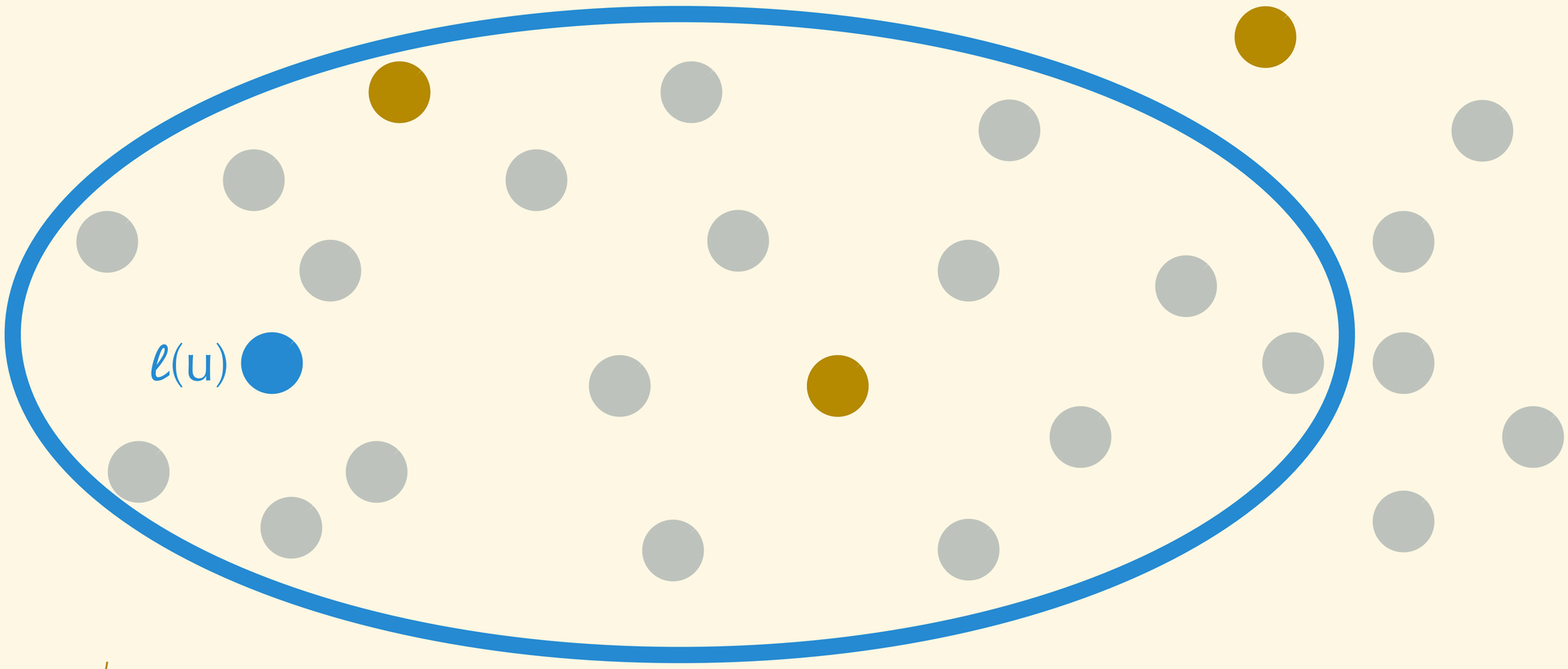
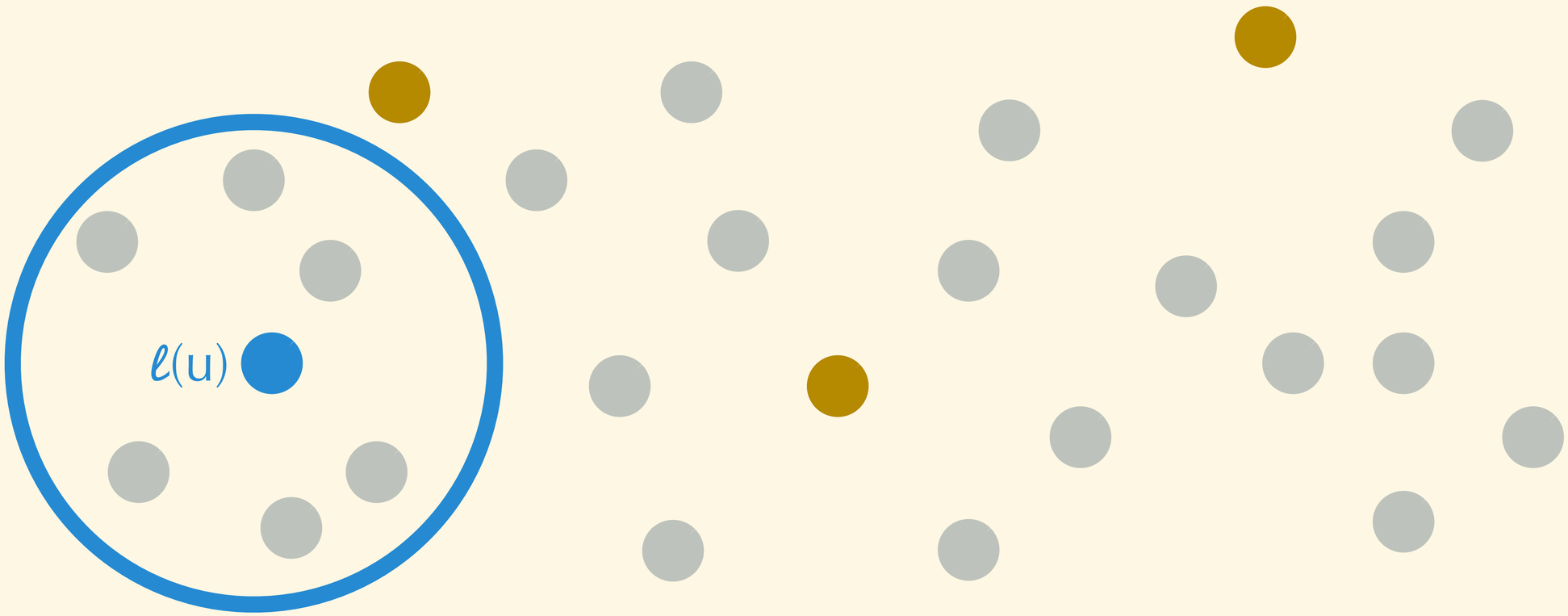


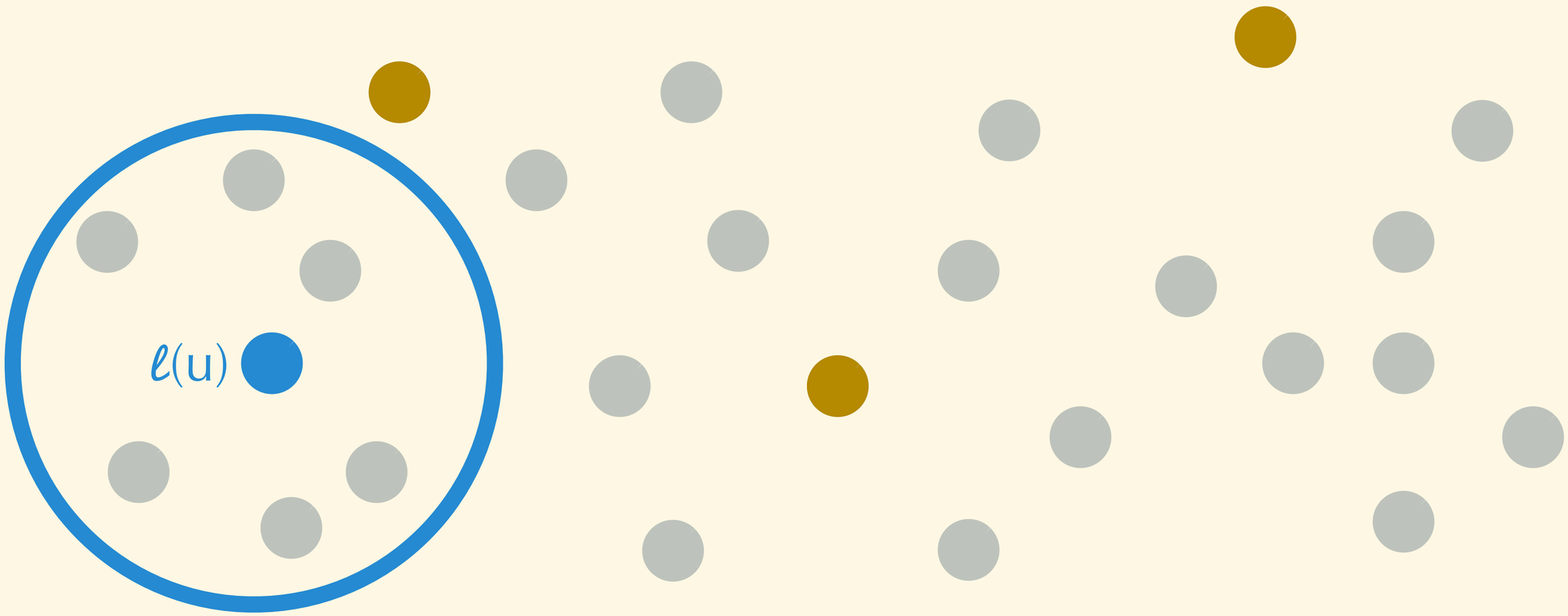
With $\sqrt{n}$ landmarks

LABELED COMPACT ROUTING SCHEME



With $\sqrt{n}$ landmarks
vicinity balls have
size $\tilde{O}(\sqrt{n})$

Labeled compact routing scheme

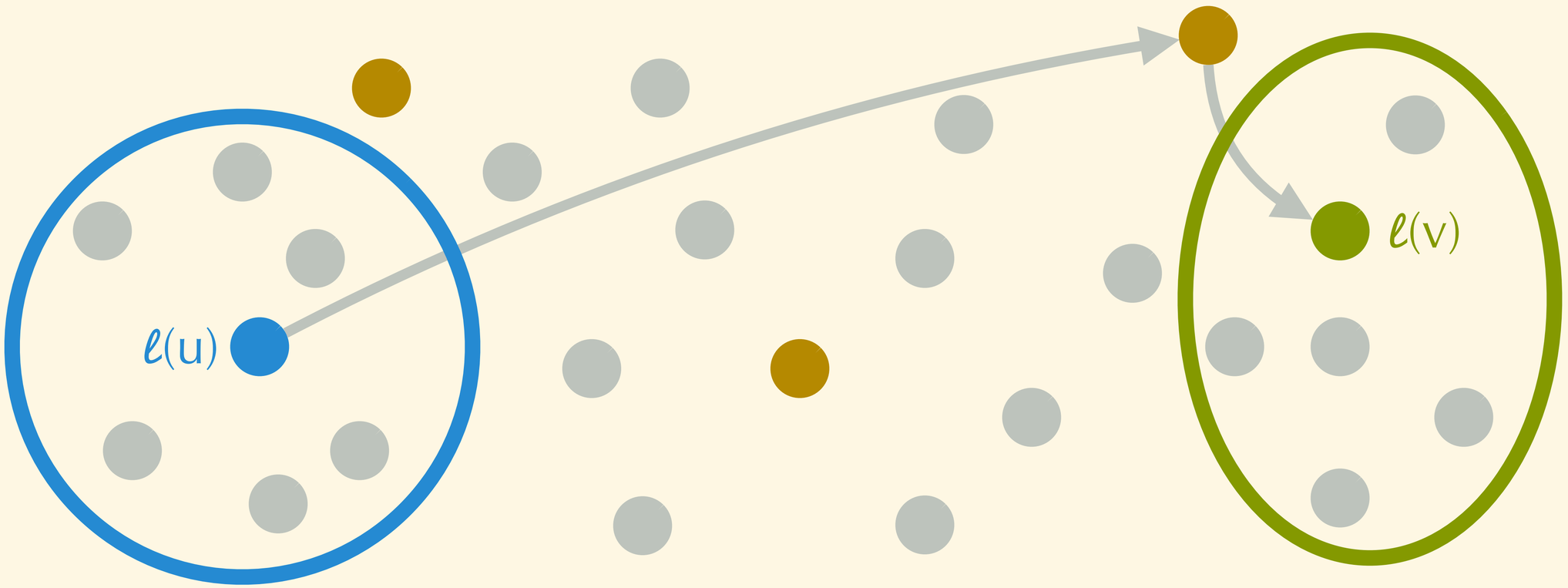


With $\sqrt{n}$ landmarks vicinity balls have size $\tilde{O}(\sqrt{n})$

For $\sqrt{n}$ landmarks nodes:

- Memory: $\tilde{O}(\sqrt{n})$
- Stretch: 3 at most
- Similar to the scheme by Thorup & Zwick [TZ'01]

Labeled compact routing scheme



For $\sqrt{n}$ landmarks nodes:

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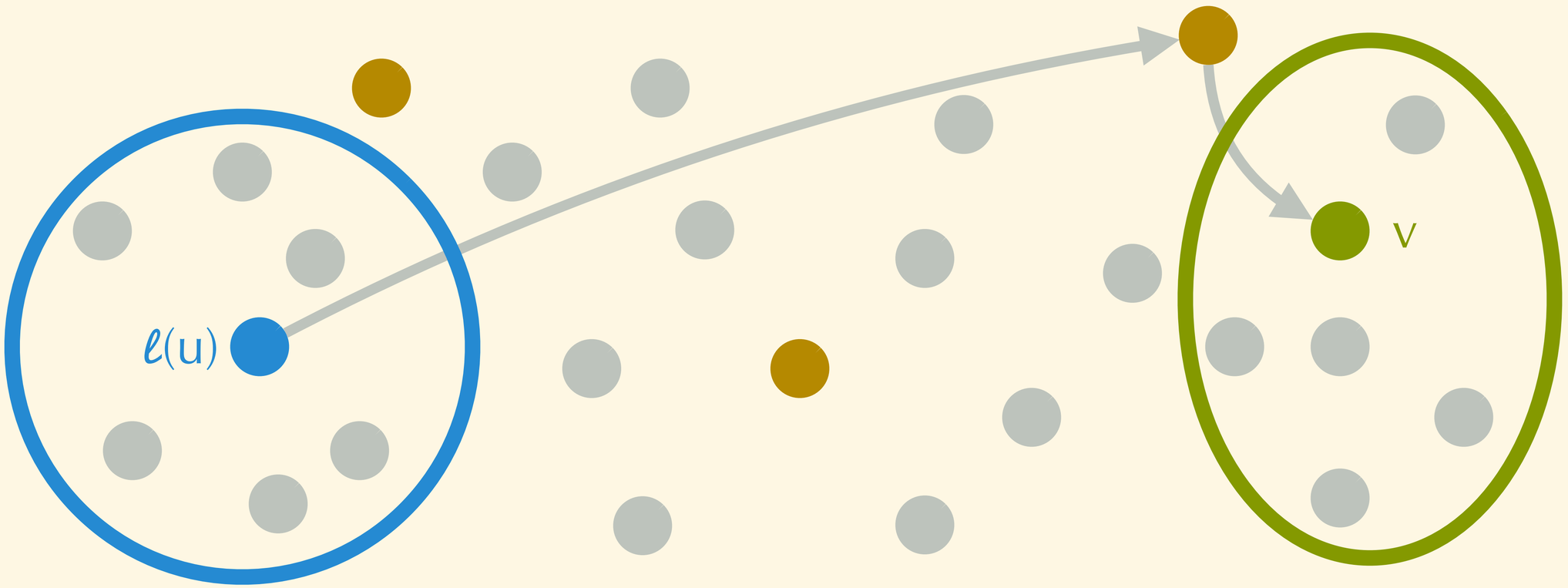
HOW TO BUILD A ROUTING SCHEME

PART III : From Labeled to Name-independent routing

Labeled compact routing scheme



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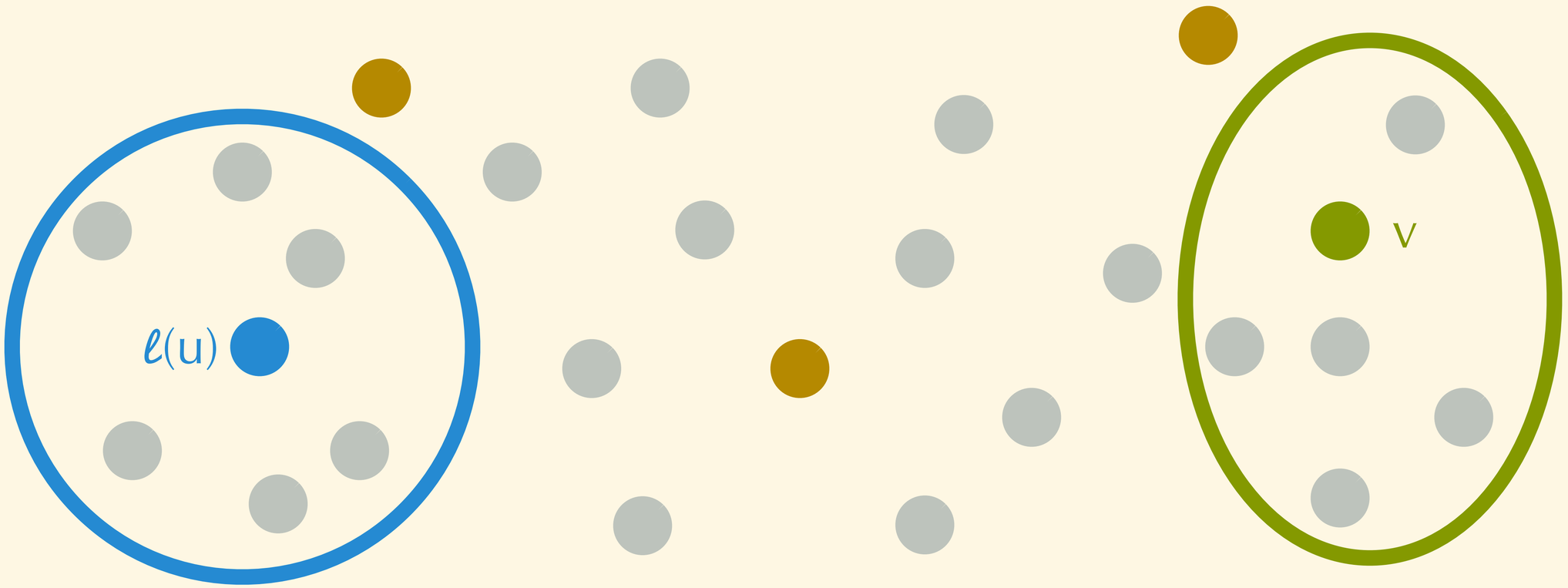


For $\sqrt{n}$ landmarks nodes:

- Memory: $\tilde{O}(\sqrt{n})$
- Stretch: 3 at most
- Similar to the scheme by Thorup & Zwick [TZ'01]

Name-independent vs. Labeled

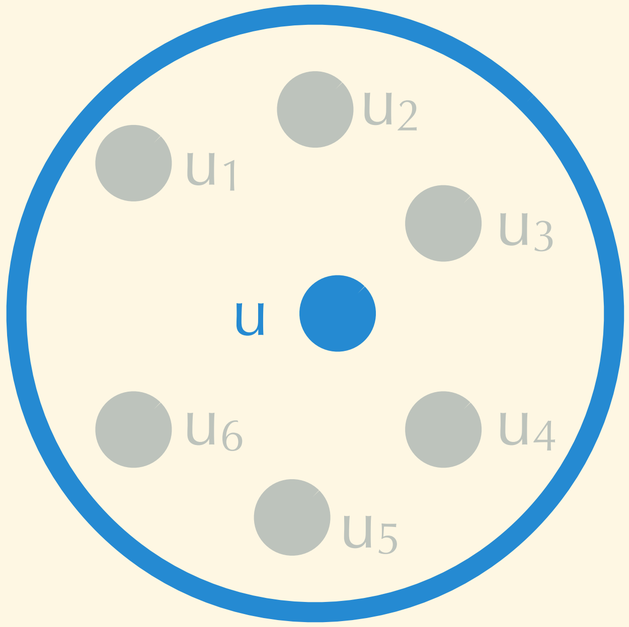
How to adapt this algorithm in the name-independent model ?

- When routing from u to v, if $\ell(u)$ and $\ell(v)$ can be retrieved then we are done.
  1. every node u could store its own label $\ell(u)$ (constant memory)
  2. every node u cannot store every destination label otherwise memory would me $O(n)$.

- The routing label $\ell(v)$ can be retrieved using local collaboration amongst vicinity nodes.

Name-independent vs. Labeled

Vicinity label-sharing

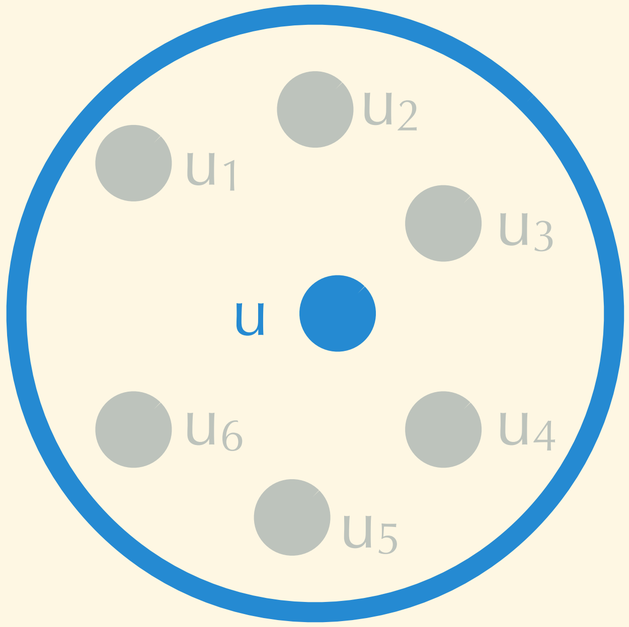


all n labels

Identifier	compact-routing-label
v_1	$\ell(v_1)$
v_2	$\ell(v_2)$
v_3	$\ell(v_3)$
v_4	$\ell(v_4)$
…	…
$v_i = v$	$\ell(v)$
…	…
v_n	$\ell(v_n)$

Name-independent vs. Labeled

Vicinity label-sharing



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…	…
v_n	$\ell(v_n)$

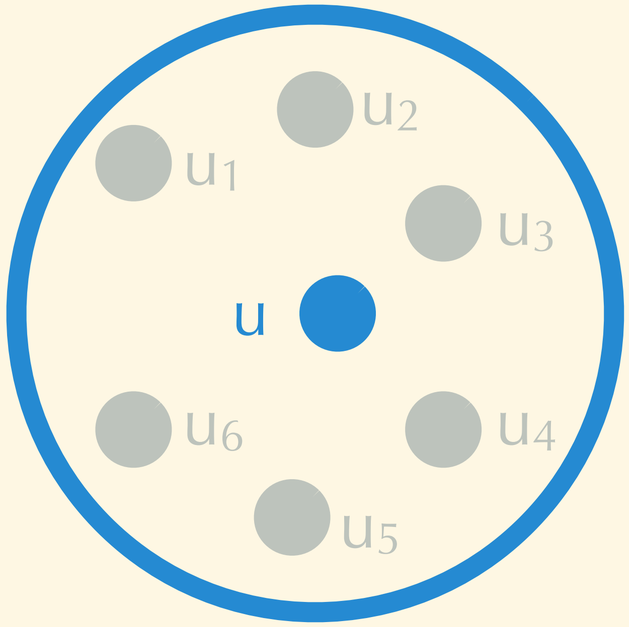
hash function $n \rightarrow \sqrt{n}$

Identifier	compact-routing-label
v_2	$\ell(v_2)$
v_3	$\ell(v_3)$
v_i	$\ell(v_i)$

Identifier	compact-routing-label
v_1	$\ell(v_1)$
v_4	$\ell(v_4)$
v_9	$\ell(v_9)$

Name-independent vs. Labeled

Vicinity label-sharing



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v_n	$\ell(v_n)$

hash function
$n \rightarrow \sqrt{n}$

u_6

Identifier	compact-routing-label
v_2	$\ell(v_2)$
v_3	$\ell(v_3)$
v_i	$\ell(v_i)$

u

Identifier	compact-routing-label
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v_4	$\ell(v_4)$
v_9	$\ell(v_9)$

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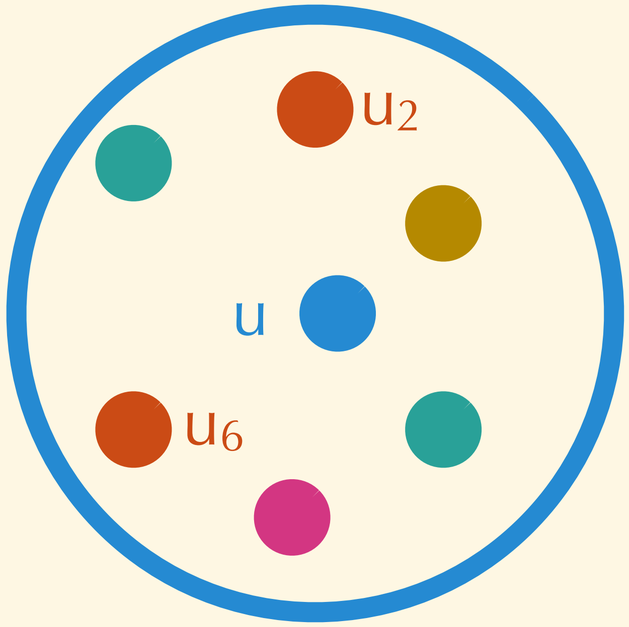

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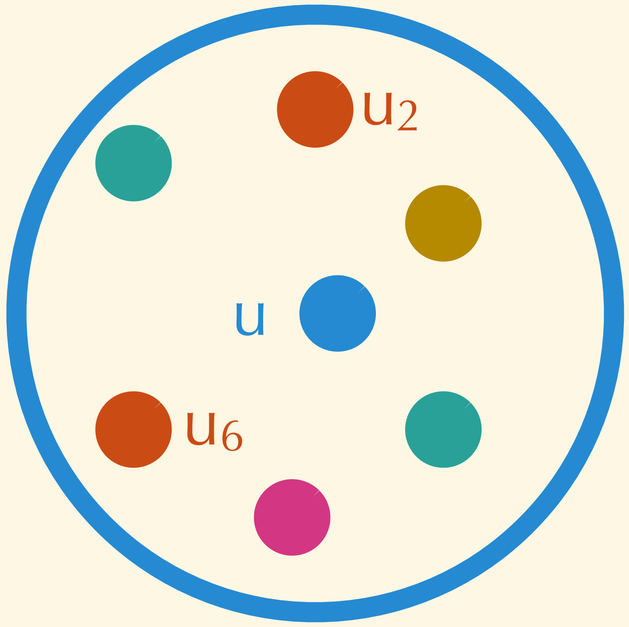

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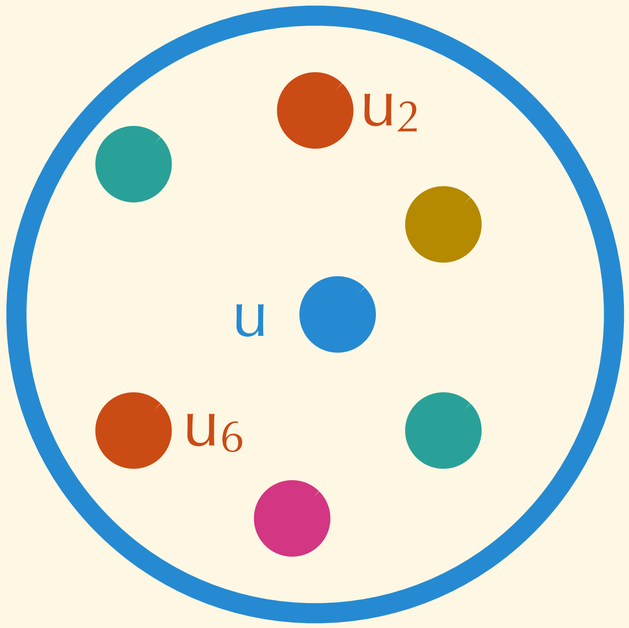

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- Moreover, in its vicinity routing table, node u stores the colours of the nodes.

Name-independent vs. Labeled

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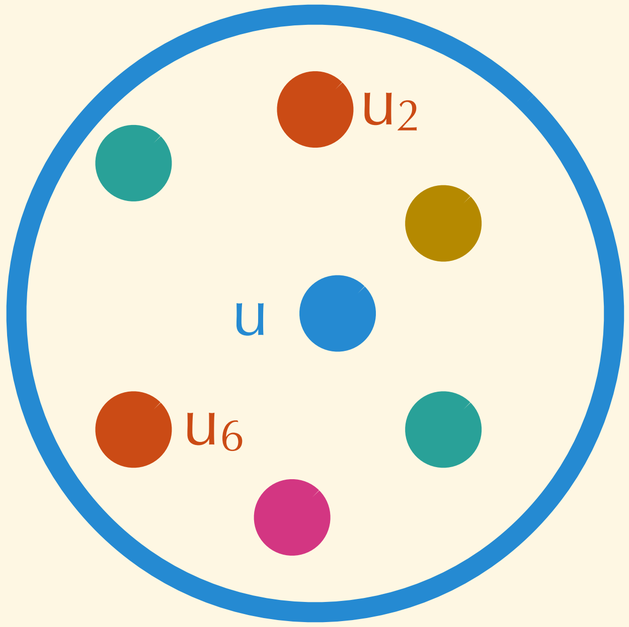

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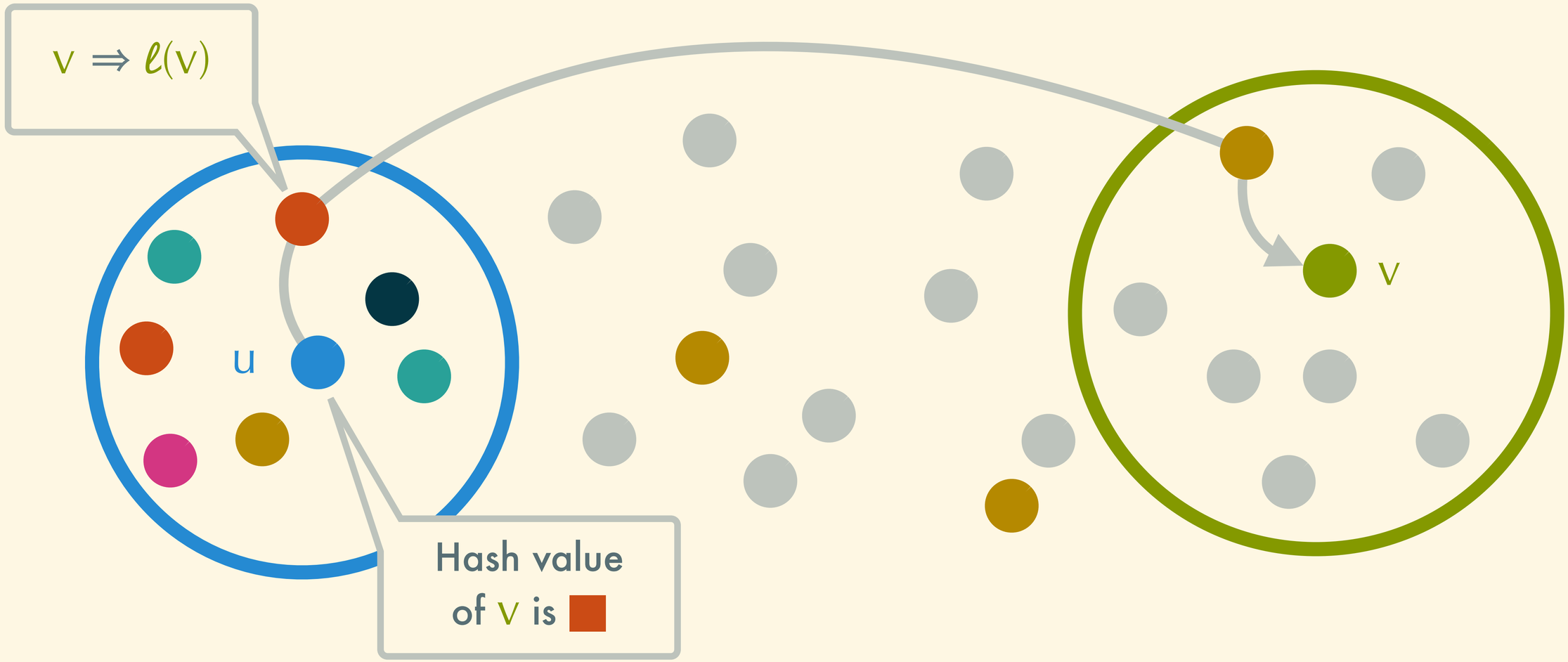
…	…
$v_i = v$	$\ell(v)$
…	…
v_n	$\ell(v_n)$

- Moreover, in its vicinity routing table, node u stores the colours of the nodes.
- The memory used for label sharing is #labels/#colors, for example it can be:

$$n/\sqrt{n} = \sqrt{n}$$

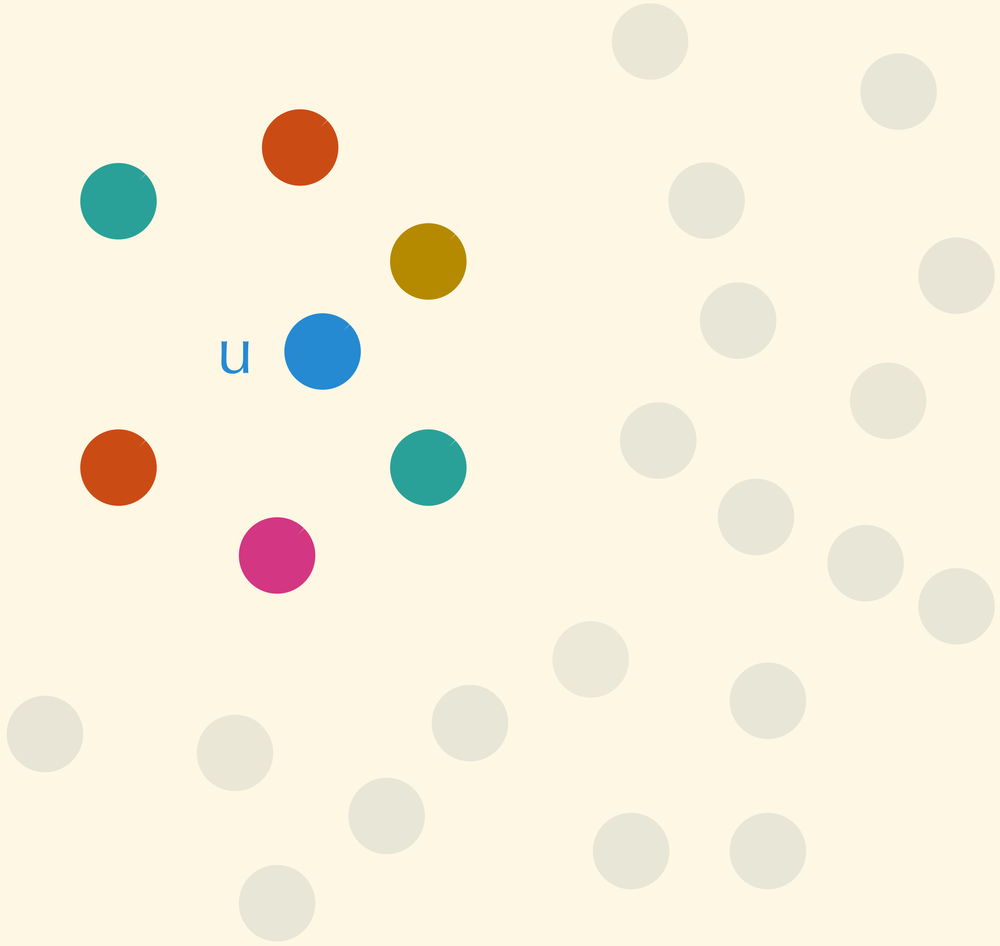
Name-independent vs. Labeled

Routing



Name-independent vs. Labeled

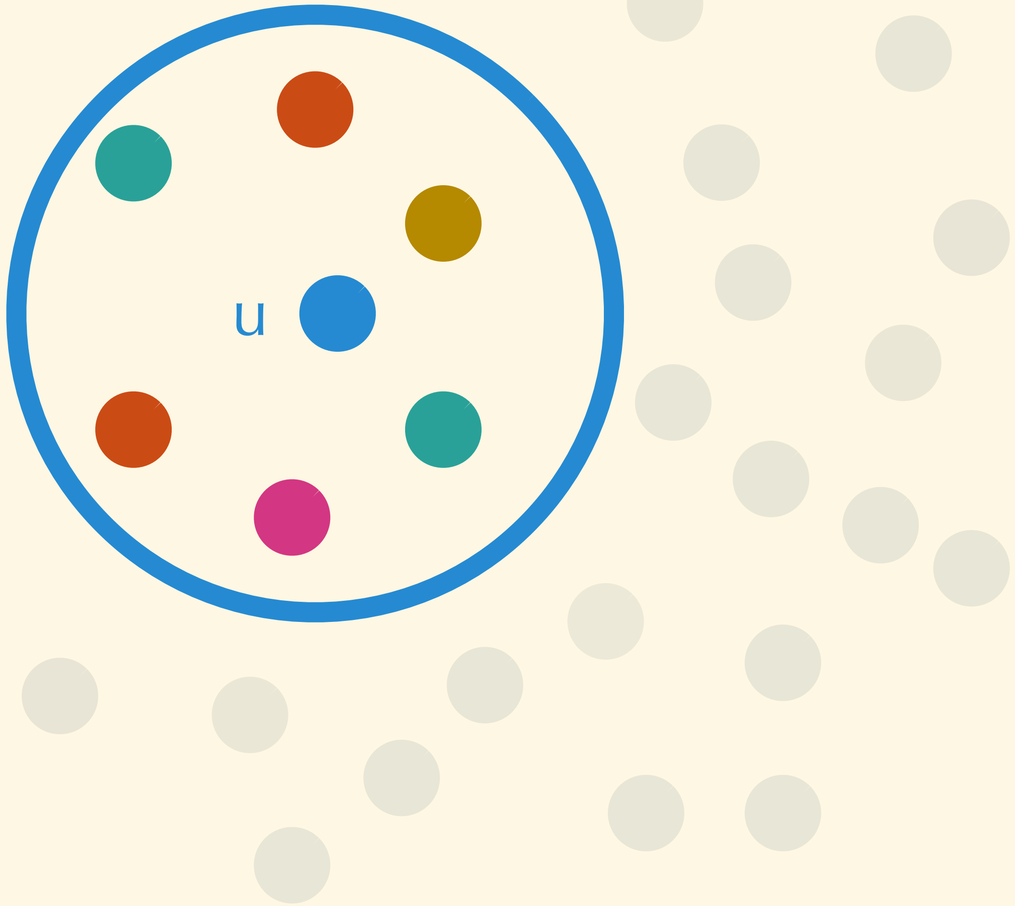
Memory



- Every node u stores two types of entries:

Name-independent vs. Labeled

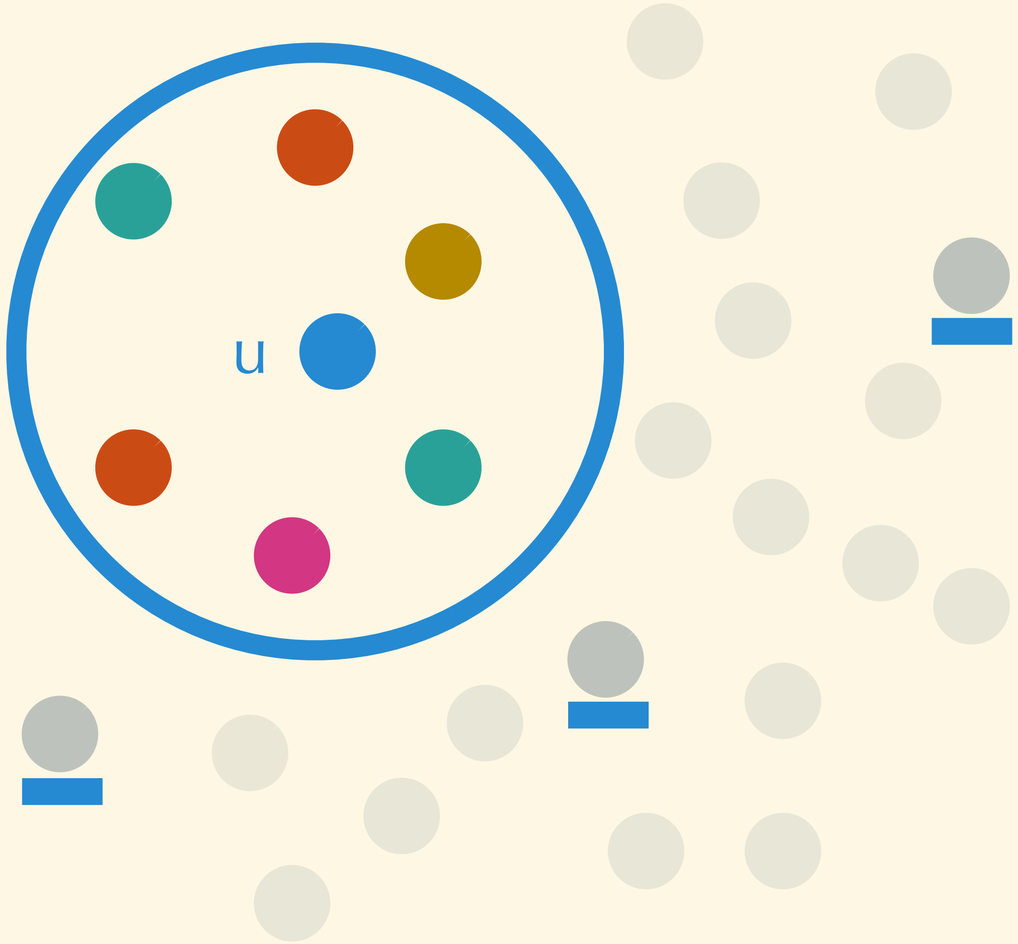
Memory



- Every node u stores two types of entries:
  - Next-hop and color of nodes in its vicinity ball, ie., $\tilde{O}(\sqrt{n})$ entries.

Name-independent vs. Labeled

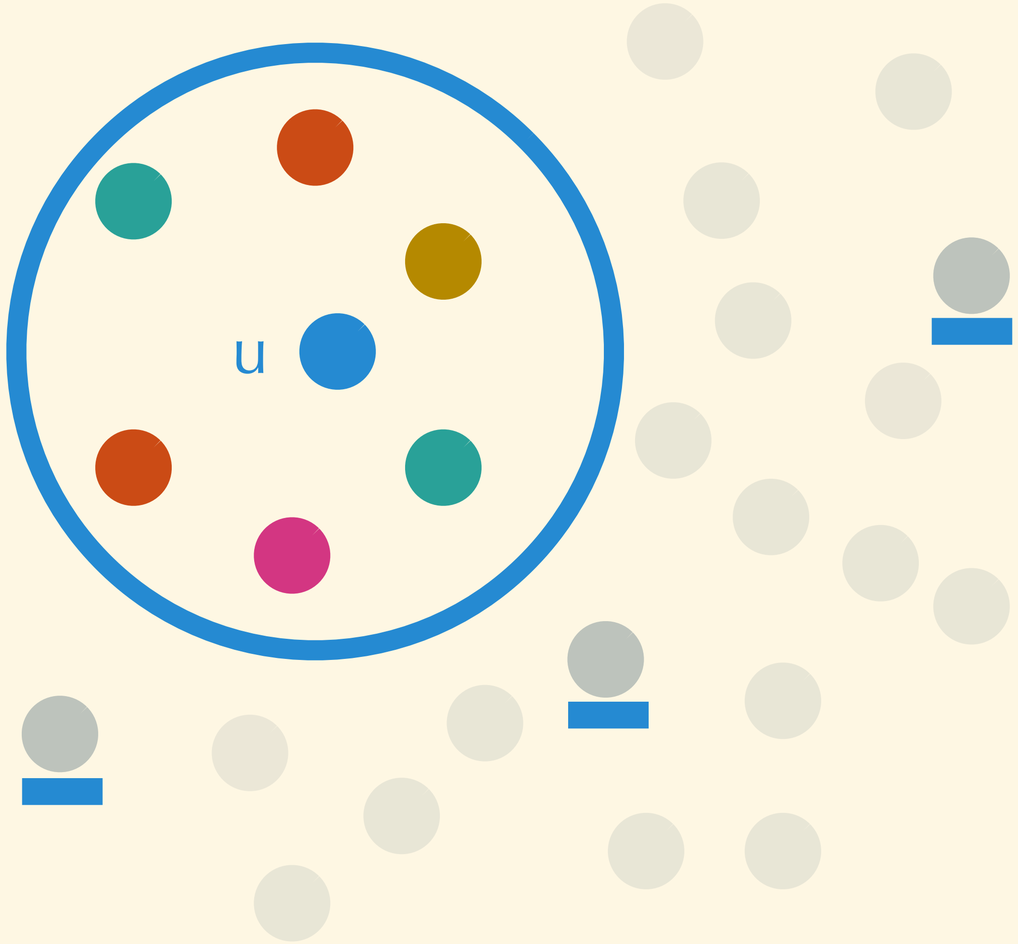
Memory



- Every node u stores two types of entries:
  - Next-hop and color of nodes in its vicinity ball, ie., $\tilde{O}(\sqrt{n})$ entries.
  - Compact routing labels of nodes whose hash value is blue, ie., $\tilde{O}(\sqrt{n})$ entries.

Name-independent vs. Labeled

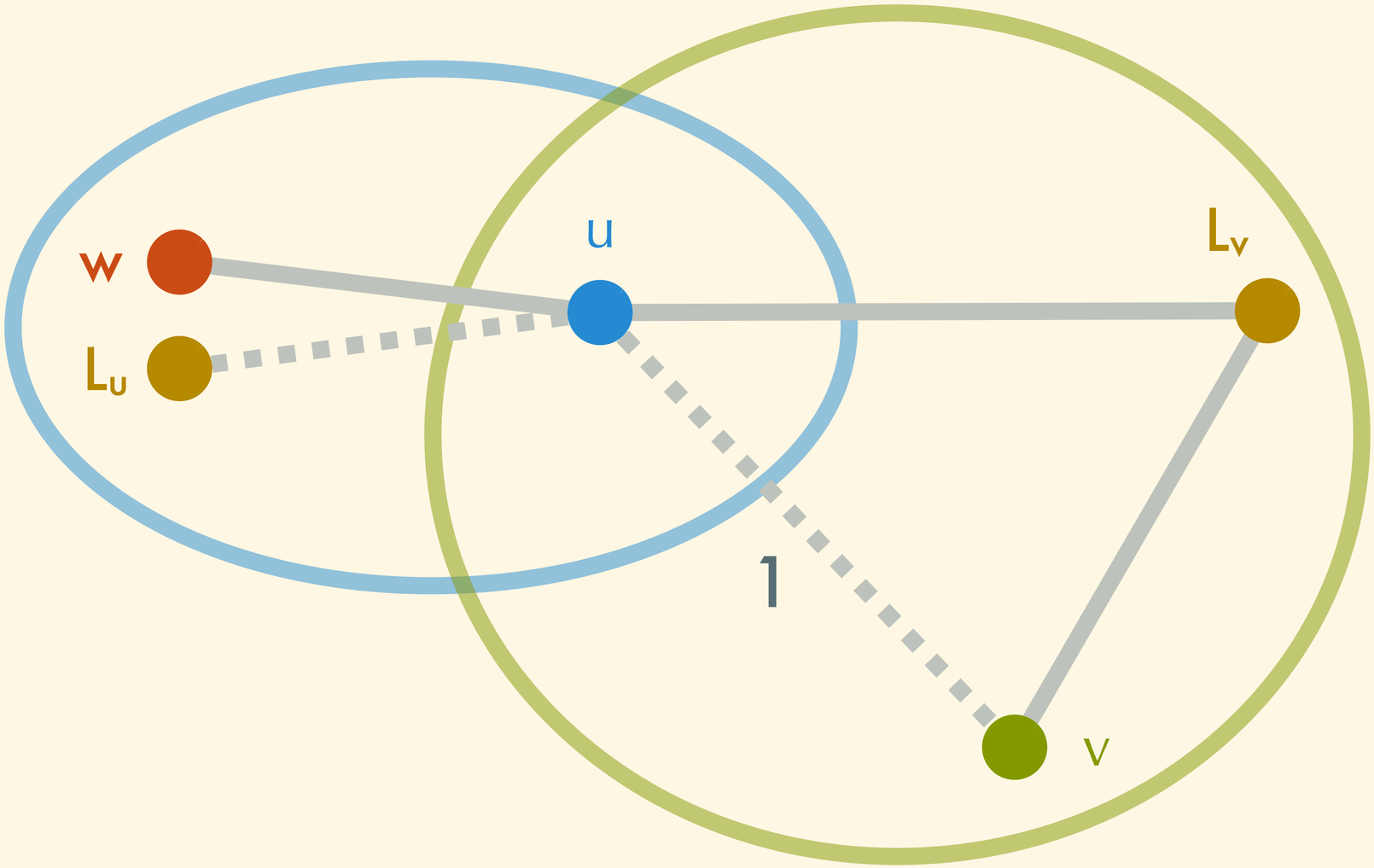
Memory



- Every node u stores two types of entries:
  - Next-hop and color of nodes in its vicinity ball, ie., $\tilde{O}(\sqrt{n})$ entries.
  - Compact routing labels of nodes whose hash value is blue, ie., $\tilde{O}(\sqrt{n})$ entries.
- Therefore, the total memory per node is $\tilde{O}(\sqrt{n})$

Name-independent vs. Labeled

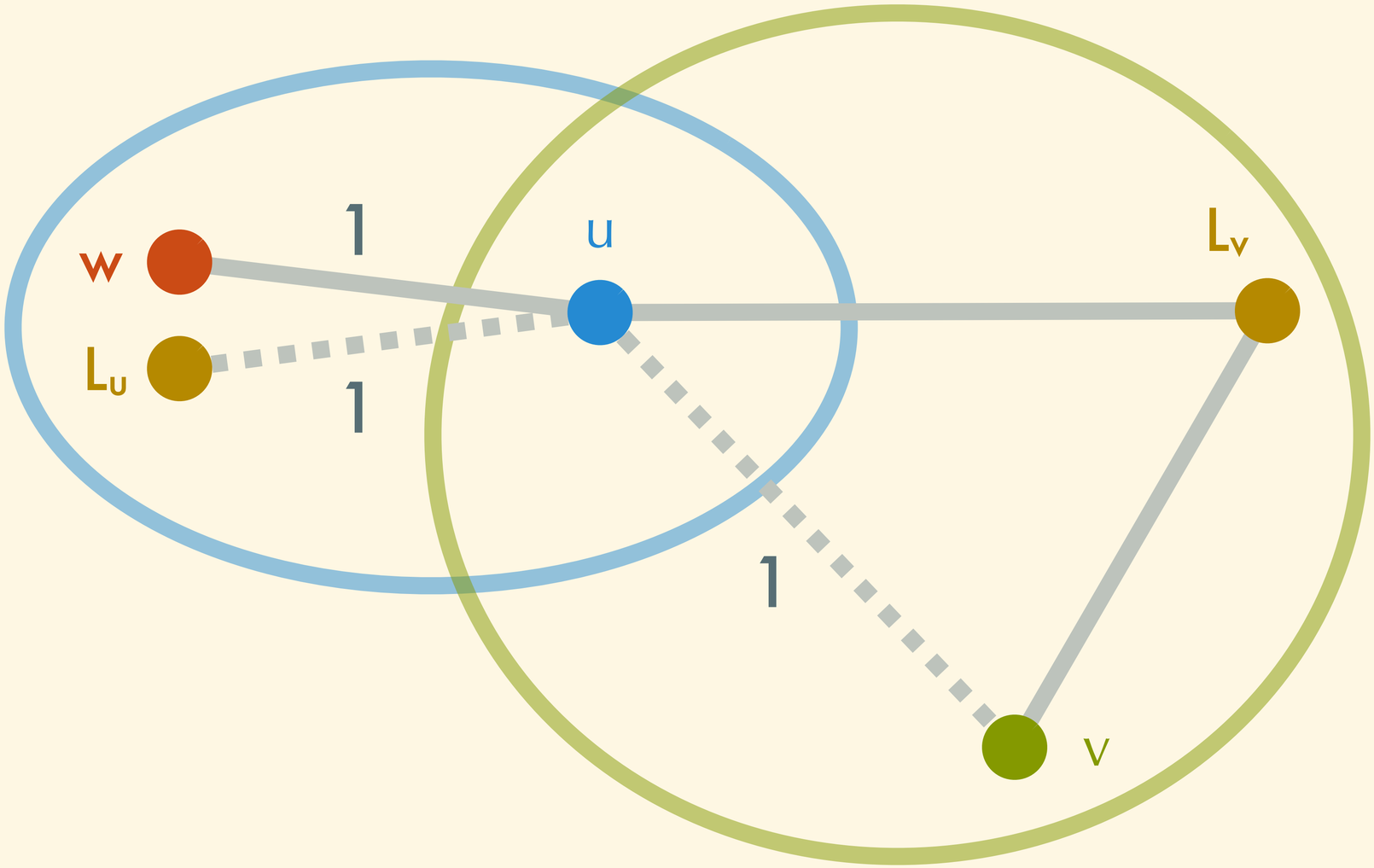
Stretch factor



- Hyp.: d(u,v) = 1

Name-independent vs. Labeled

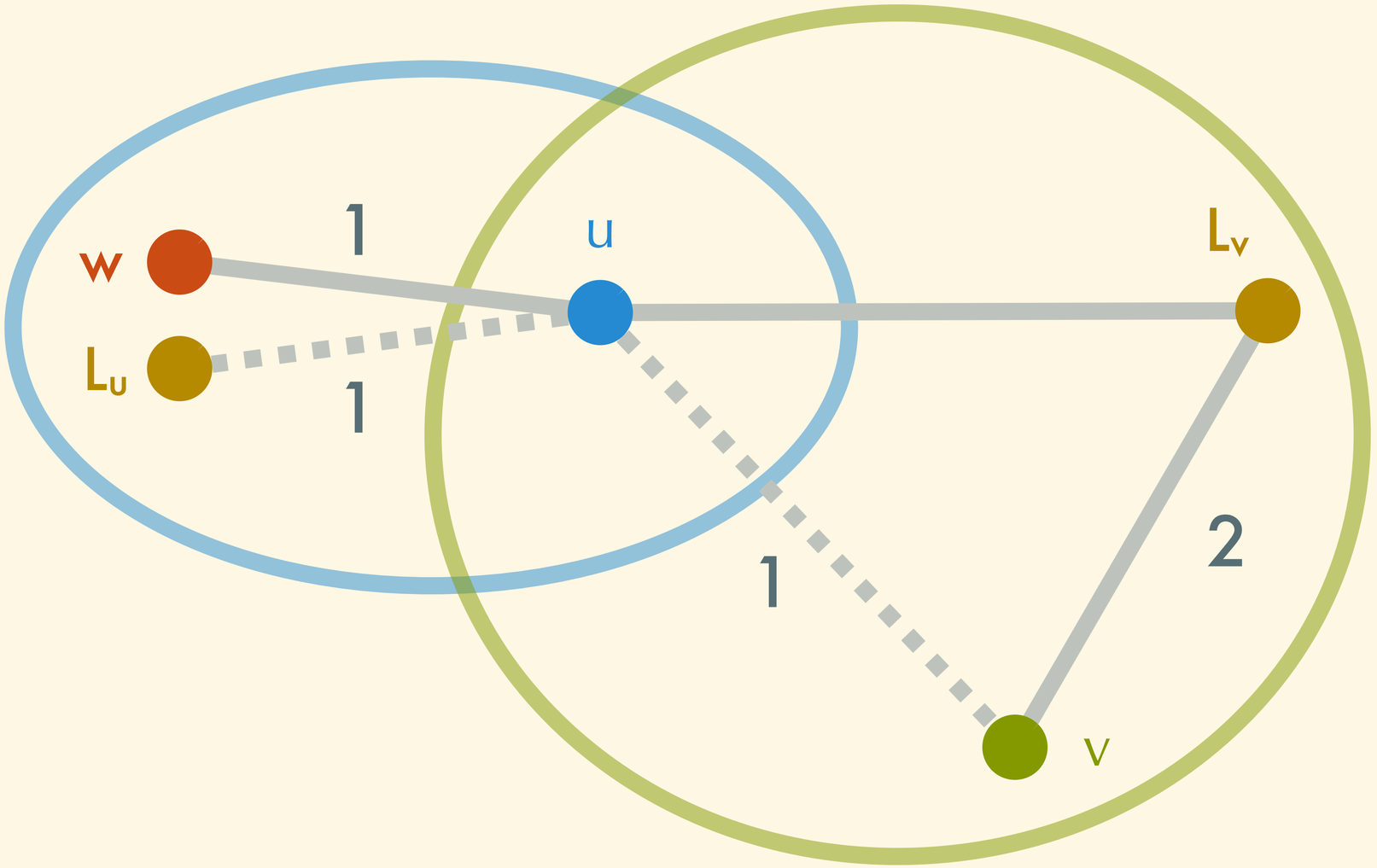
Stretch factor



- Hyp.: d(u,v) = 1
- ⇒ Radius ≤ 1

Name-independent vs. Labeled

Stretch factor

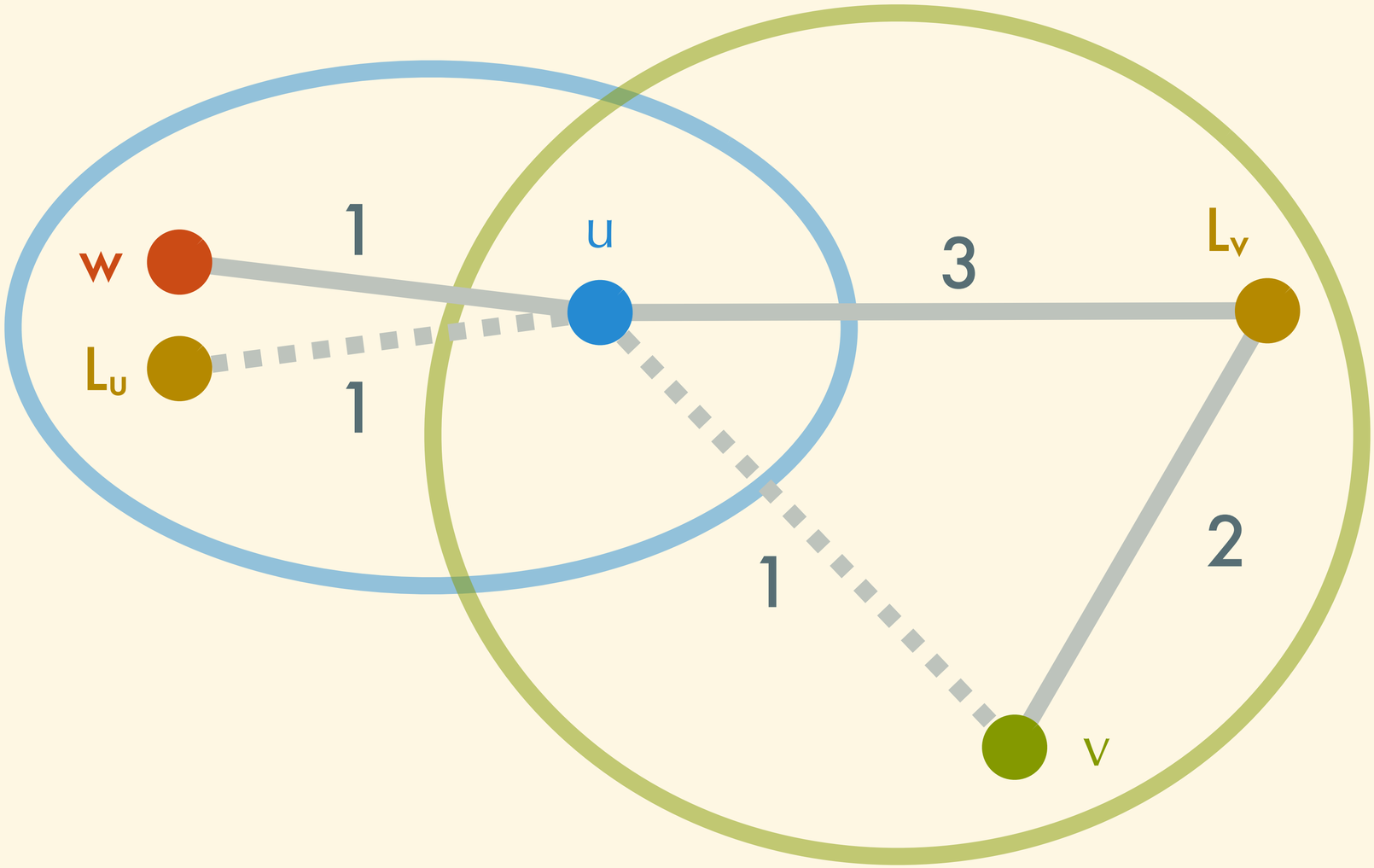


- Hyp.: d(u,v) = 1
- ⇒ Radius ≤ 1

- $d(v,L_v) \leq d(v,L_u) \leq 2$

Name-independent vs. Labeled

Stretch factor

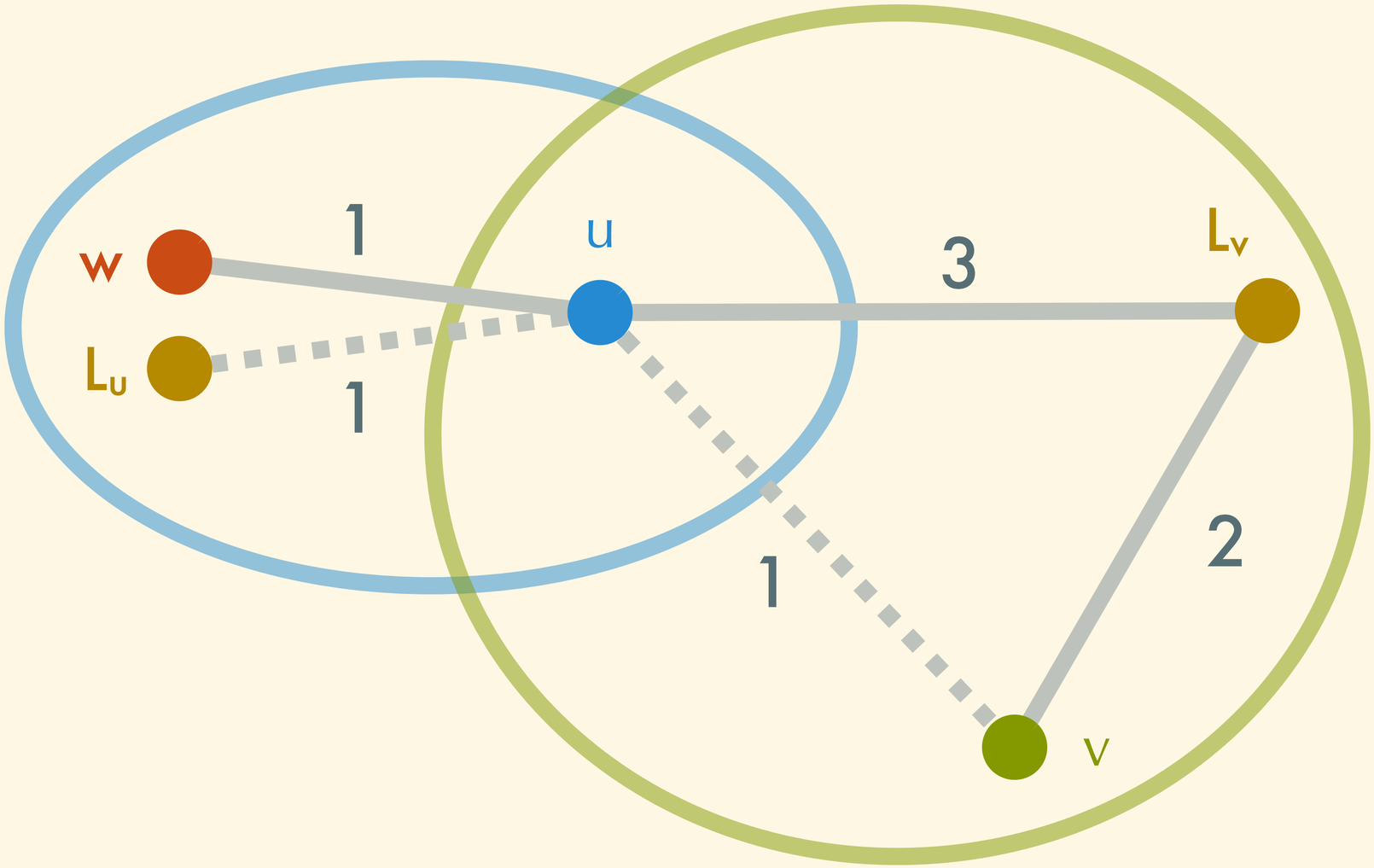


- Hyp.: d(u,v) = 1
- ⇒ Radius ≤ 1

- $d(v,L_v) \le d(v,L_u) \le 2$
- $d(u,Lv) \le d(v,Lv)+d(u,v) \le 3$

Name-independent vs. Labeled

Stretch factor



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- $d(v,L_v) \le d(v,L_u) \le 2$
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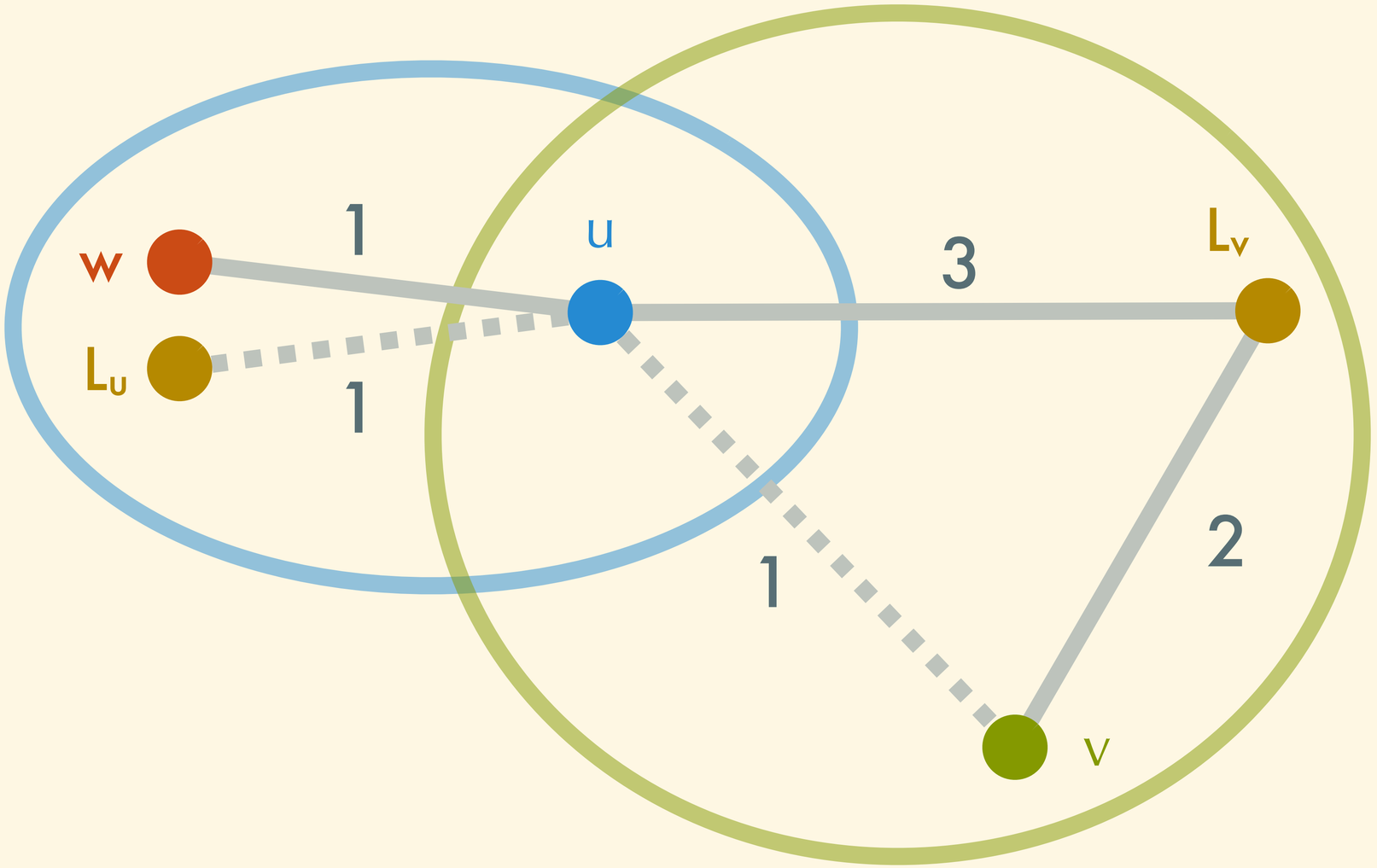
- "u ⇝ w ⇝ u ⇝ Lv ⇝ v ≤ 7"

Name-independent vs. Labeled

Stretch factor



- Hyp.: d(u,v) = 1
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- $d(v,L_v) \le d(v,L_u) \le 2$
- $d(u,Lv) \le d(v,Lv)+d(u,v) \le 3$

- "u ⇝ w ⇝ u ⇝ Lv ⇝ v ≤ 7"
- Therefore the stretch is ≤ 7.

PERFORMANCES

	Stretch		Memory	Communication cost
[AGM'08]	3	optimal	$\tilde{O}(\sqrt{n})$	centralised
→ [GGHI'13]	7		$\tilde{O}(\sqrt{n})$	$O(m\sqrt{n})$
my thesis	5		$\tilde{O}(\sqrt{n})$	$O(m\sqrt{n})$
To be done (hard)	3		$\tilde{O}(\sqrt{n})$	$o(mn)$

- If the route use the best landmark from $\{L_u, L_v\}$ the stretch can be improved to 5.
- This can even be done in a distributed way without any impact on the asymptotic complexities.

COMPACT ROUTING FOR INTERNET-LIKE GRAPHS

Internet-like graphs

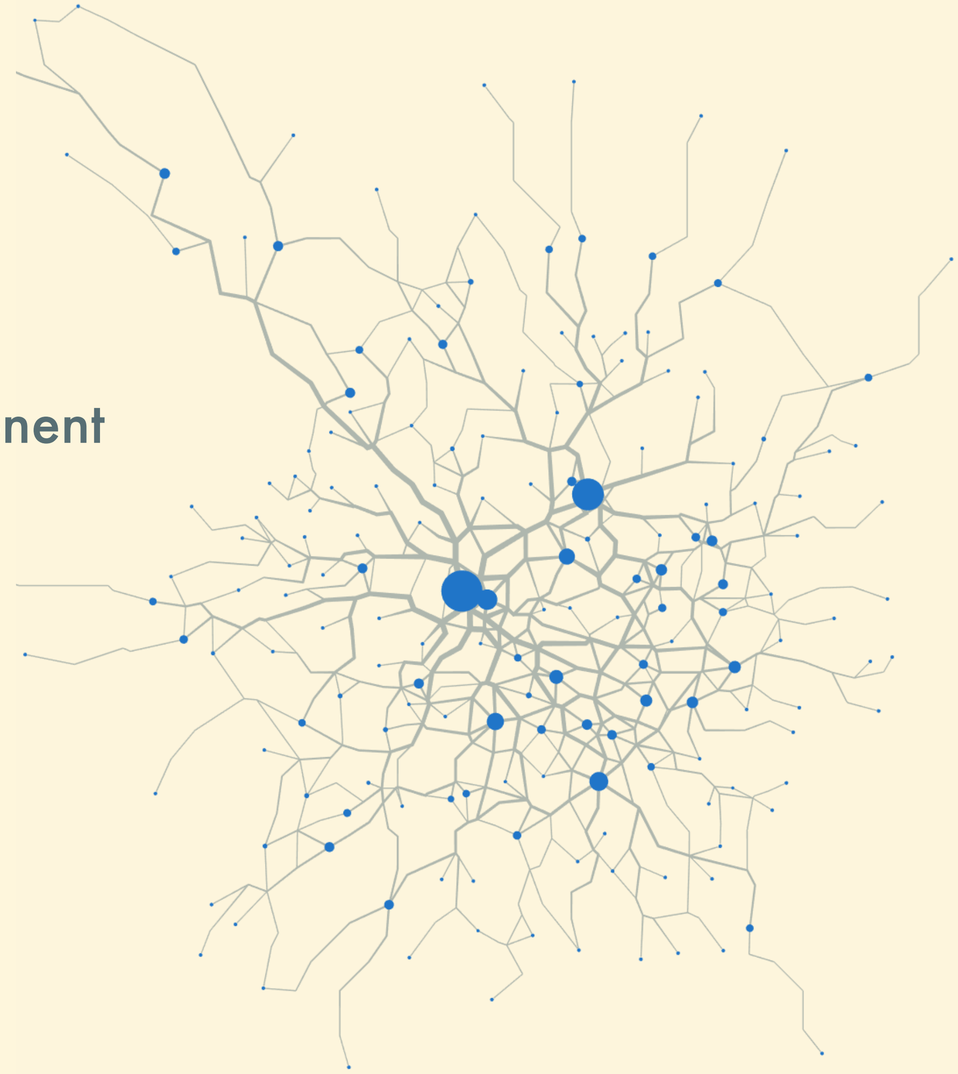
- Power-law degree distribution
  - Sparse graph (logarithmic average degree)
  - Low diameter (also logarithmic)
- Looks like a tree with a dense cluster as a root
- Mimicked by a synthetic graph model, called RPLG:
  - Random Power Law Graph
  - Parametrised by the power-law exponent, t

INTERNET-LIKE GRAPHS

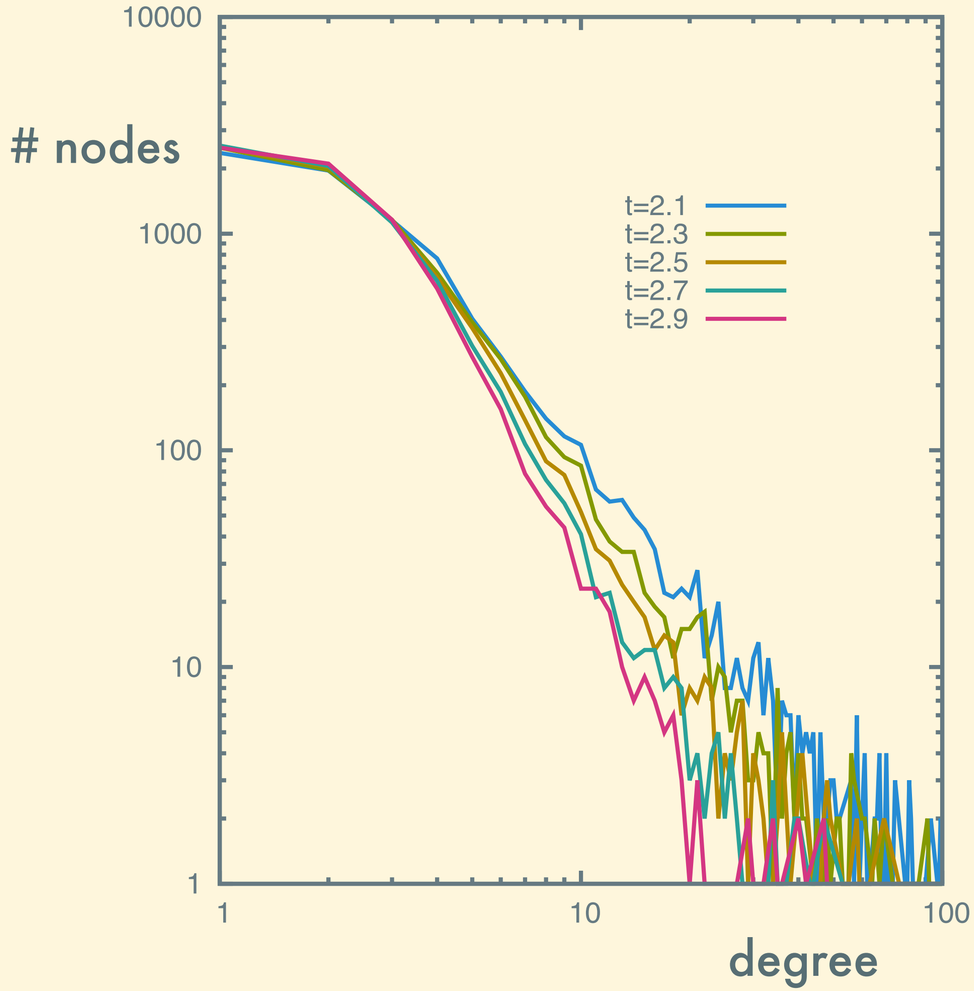
(RPLG)

Power-law exponent

t = 2.1

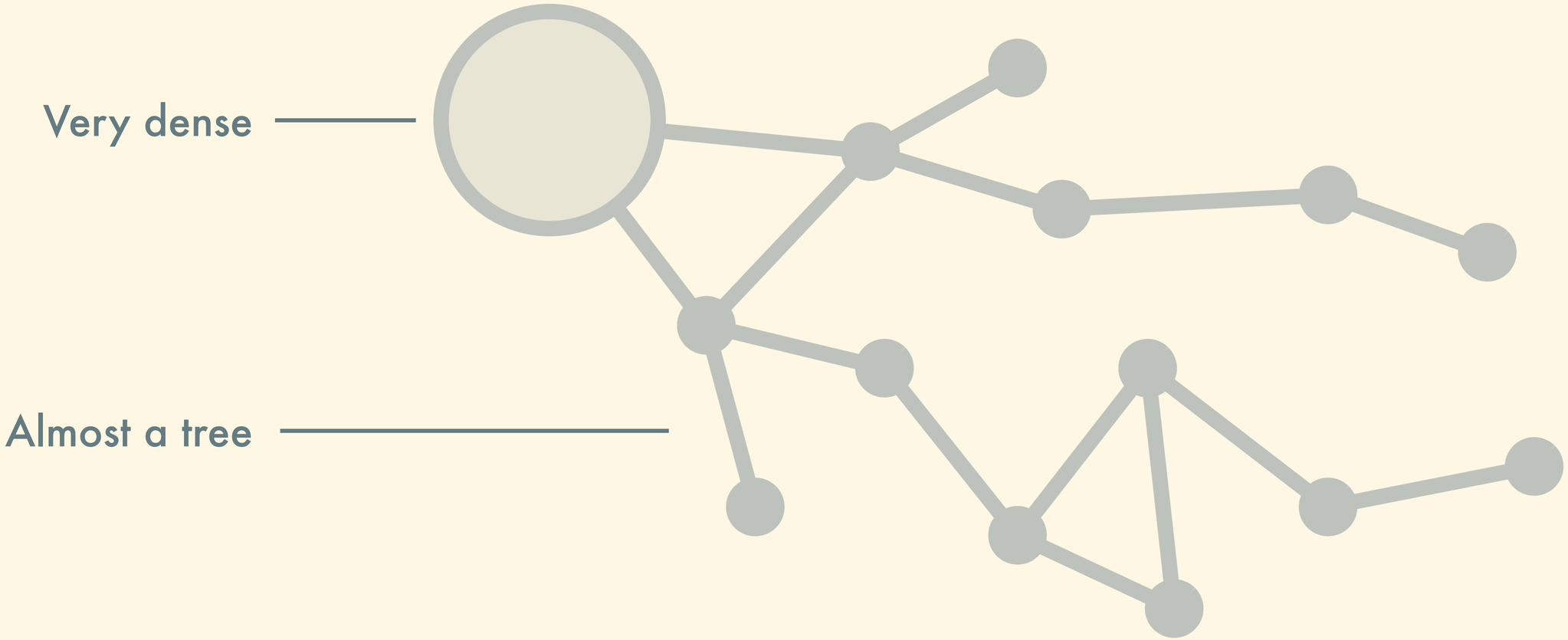


degree distribution



Improving memory performances

How to use the structure to save some entries?



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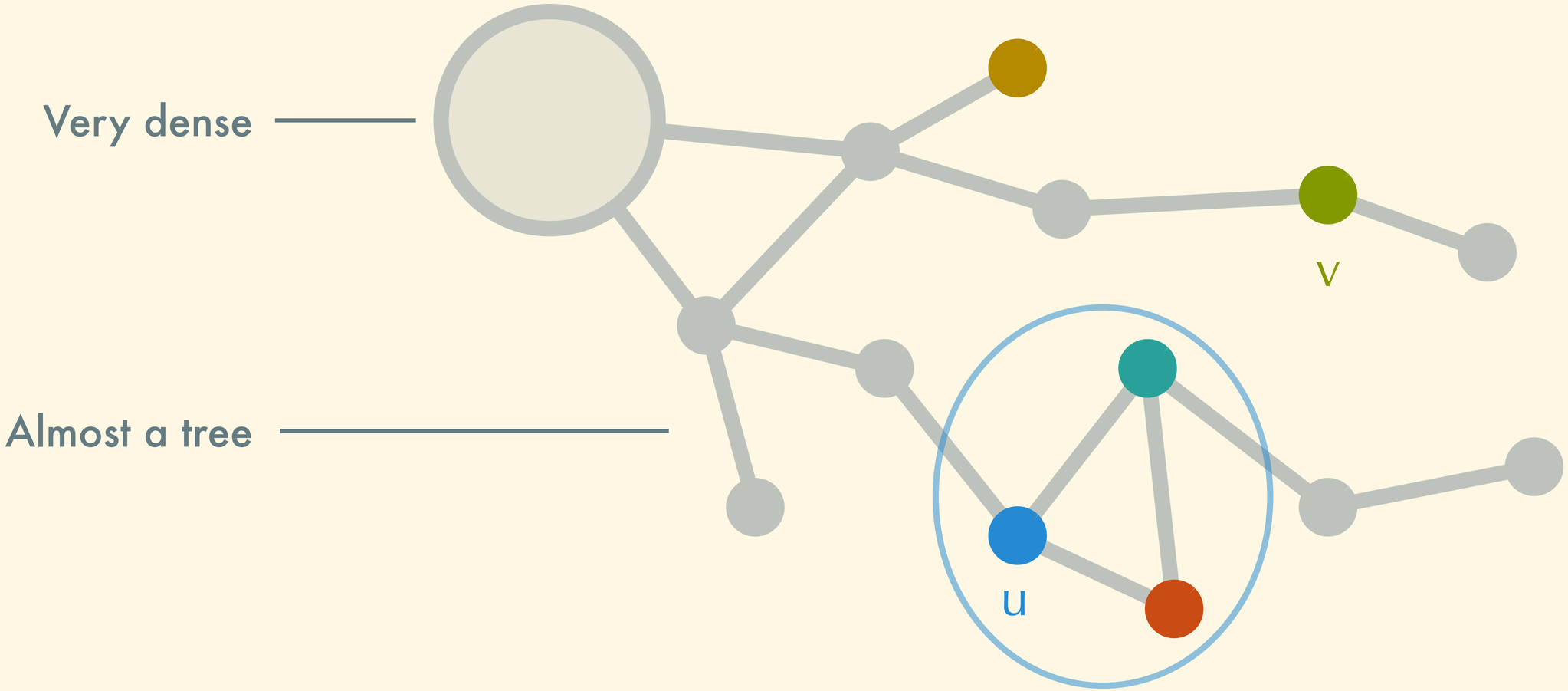

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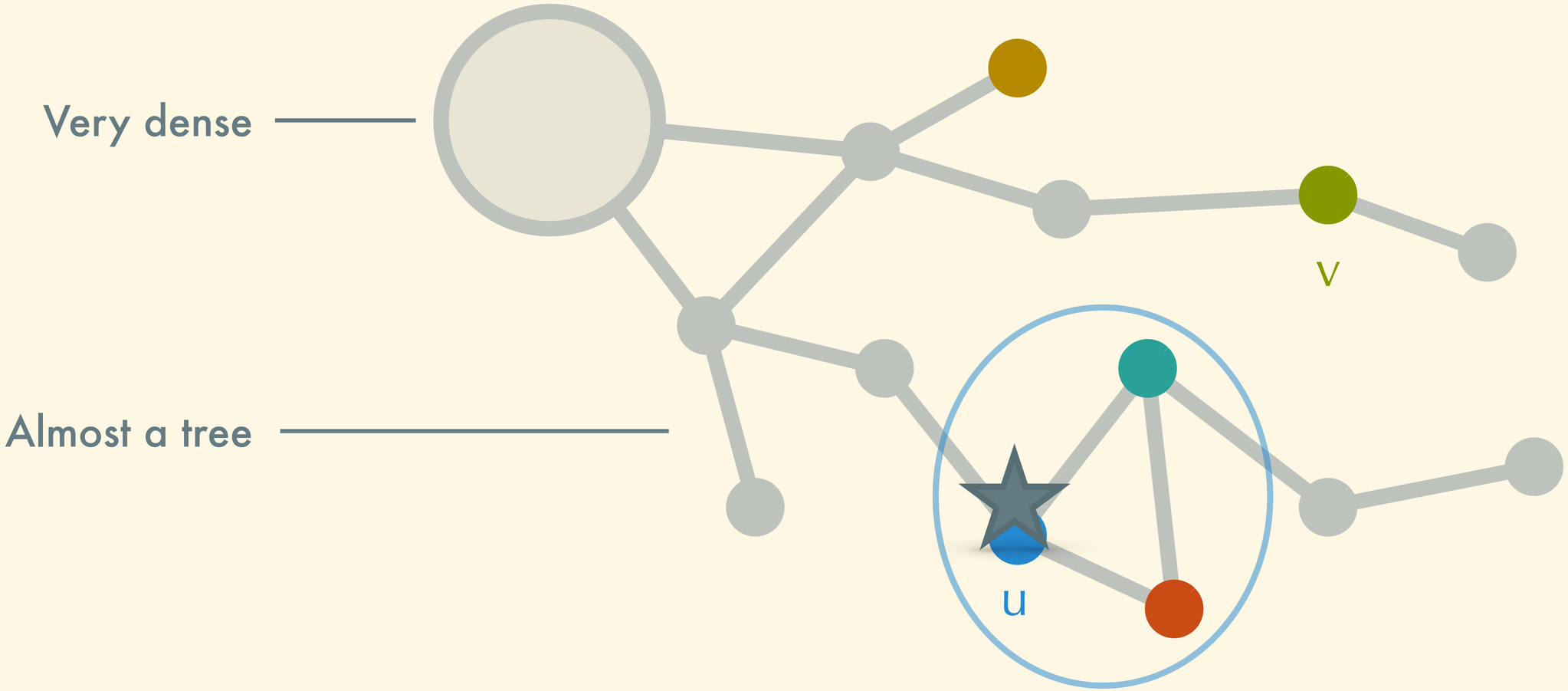

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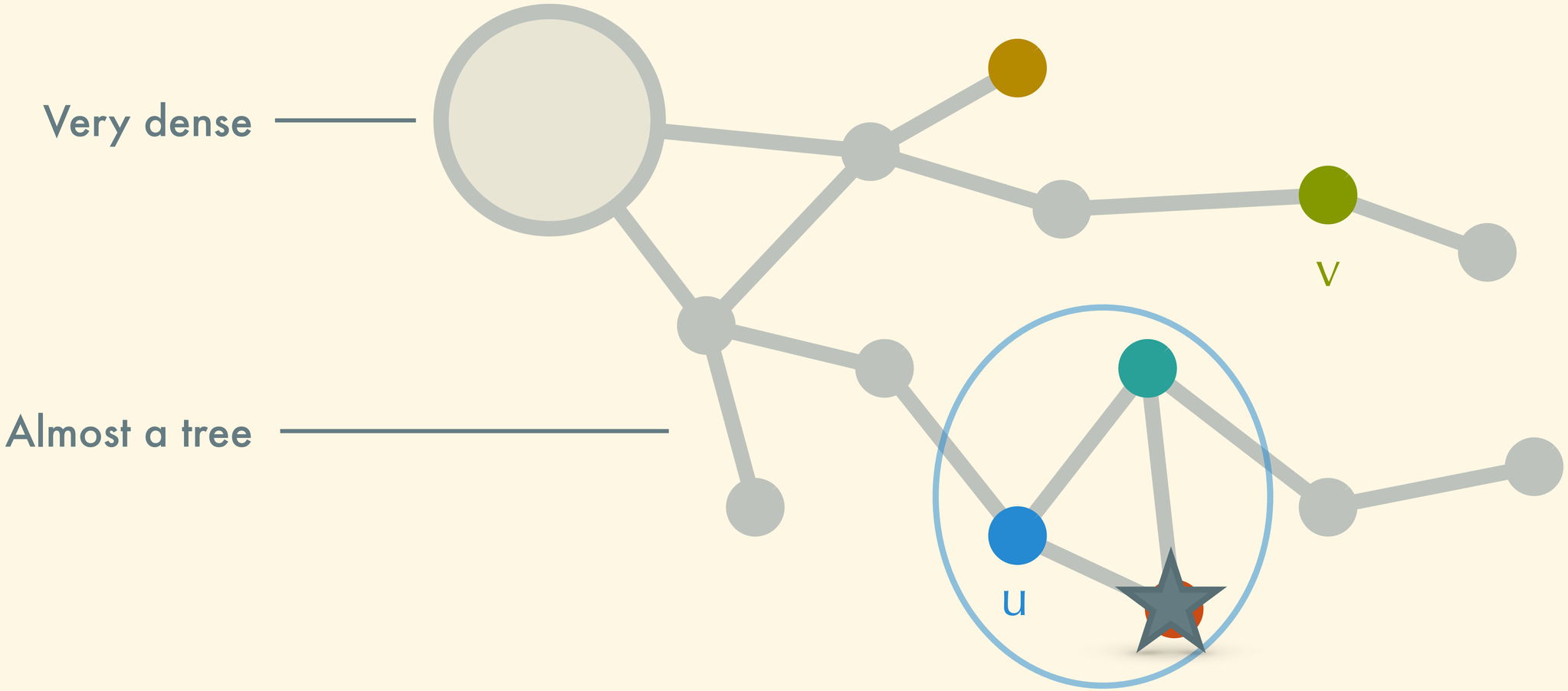

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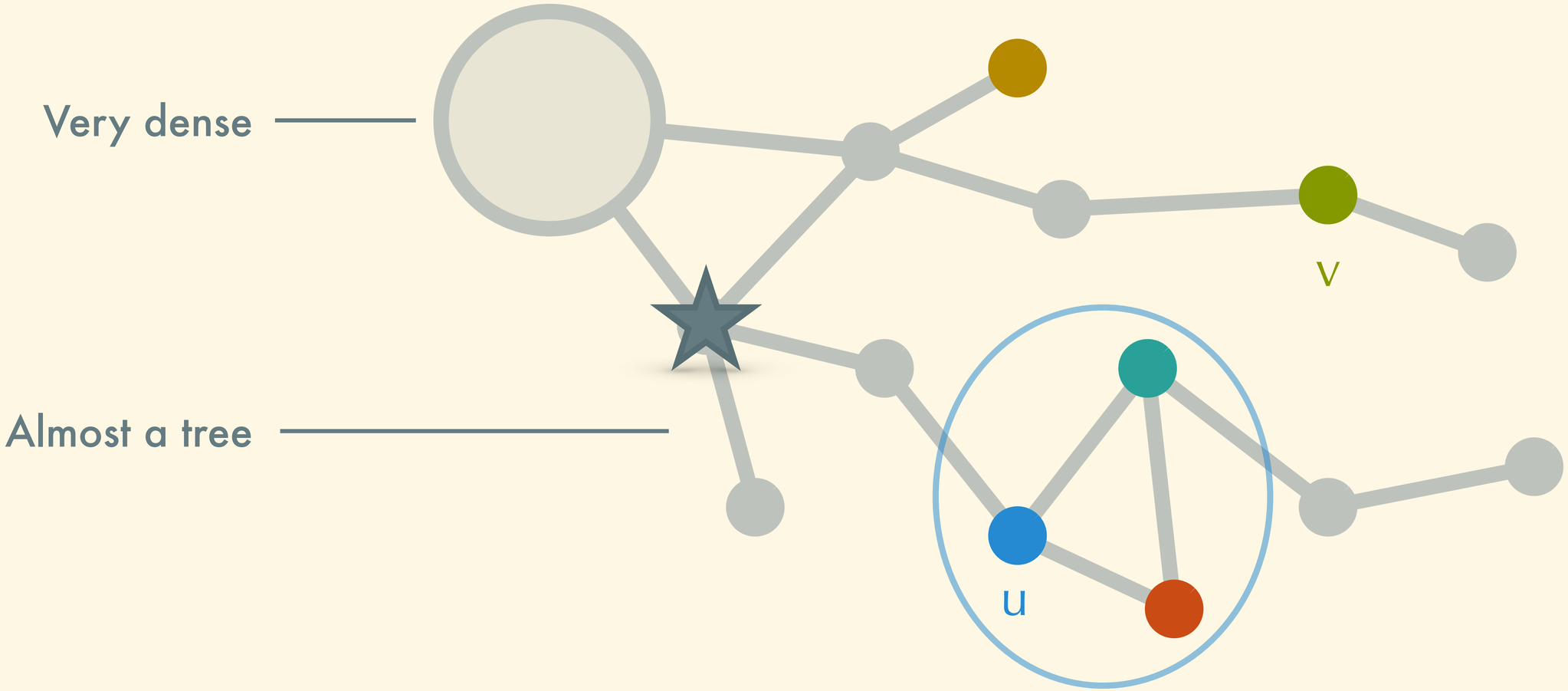

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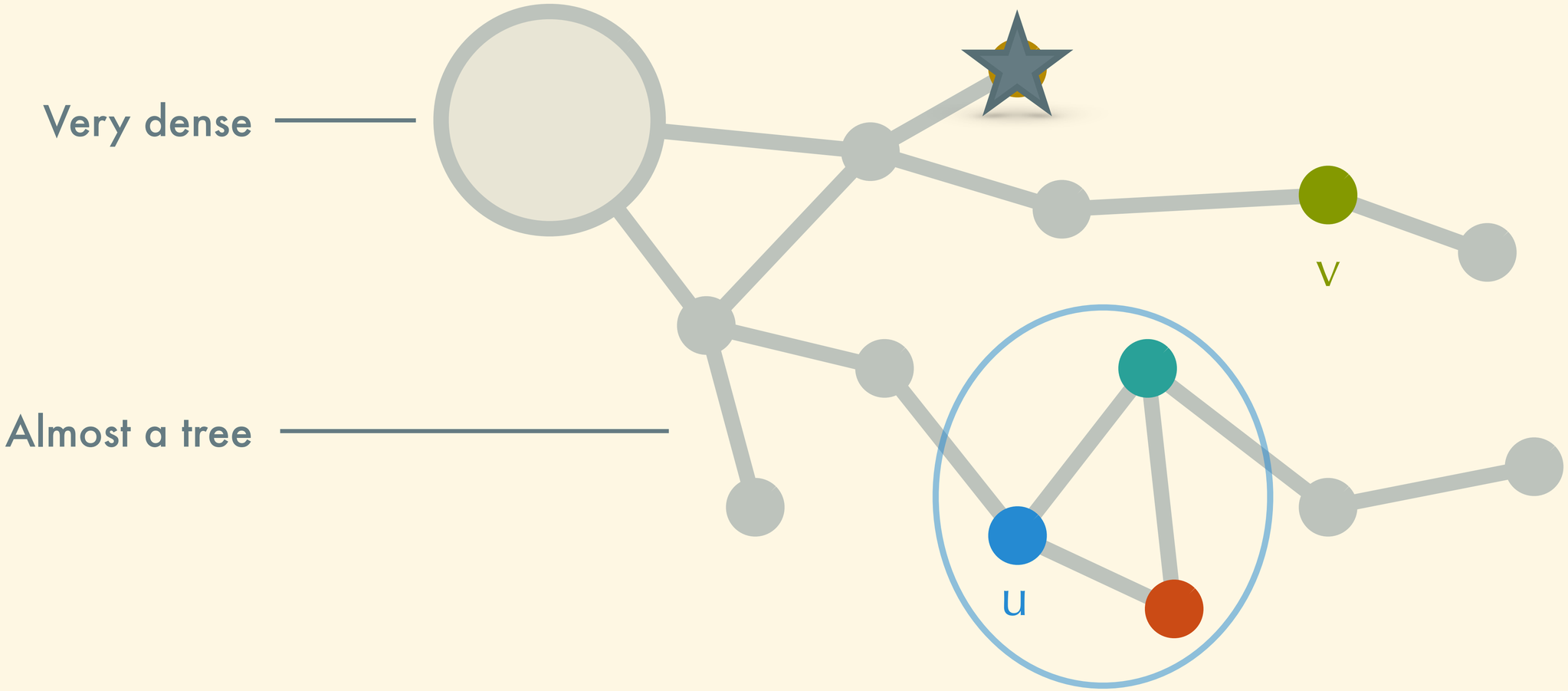

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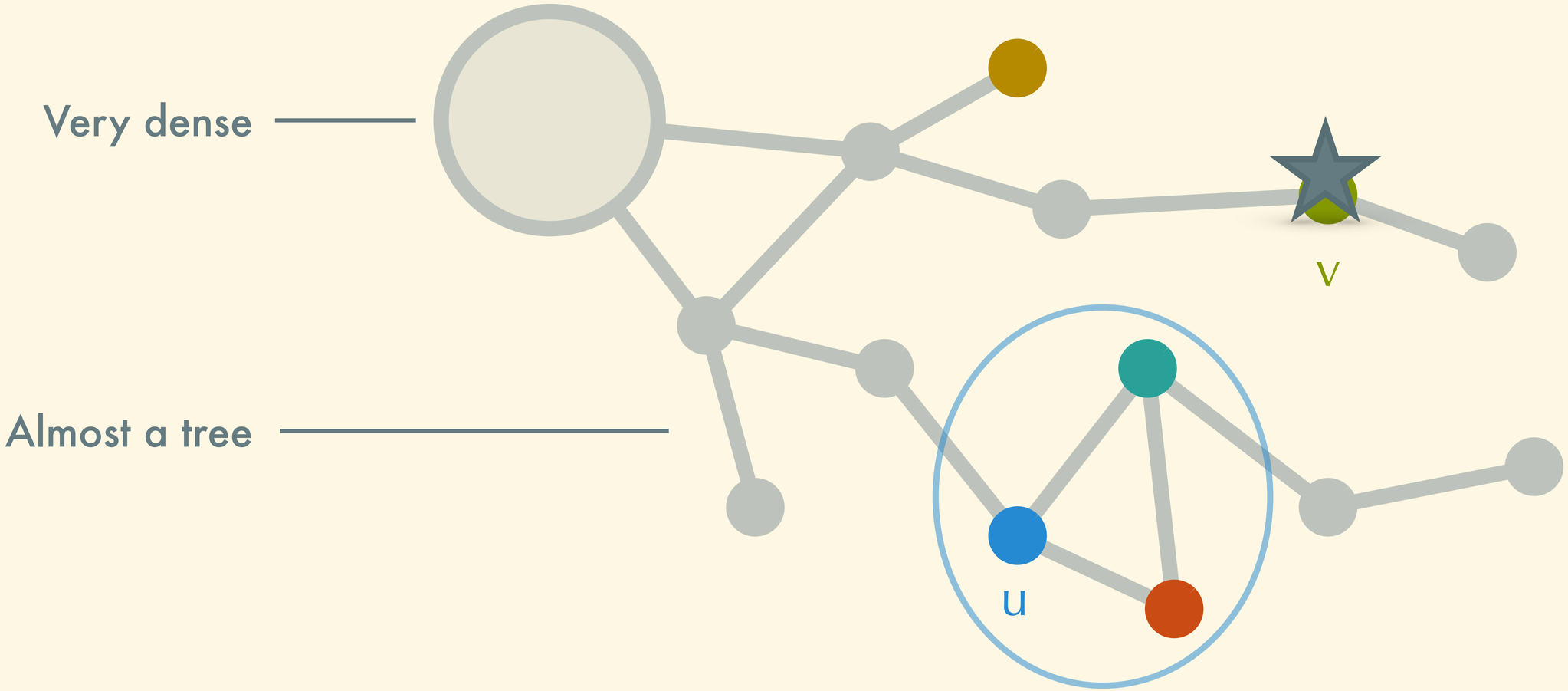

Improving memory performances

How to use the structure to save some entries?

- We are actually very used in routing with these settings, lets think about this
  - Low memory
  - Low stretch
  - Dense center
  - Very sparse outside the center
  - Most of the destinations are outside the center

Improving memory performances

How to use the structure to save some entries?

- We are actually very used in routing with these settings, lets think about Public transportation
  - Low memory - New city “there’s no one around and your phone is dead”*
  - Low stretch - Its holidays, you can’t wait in transports
  - Dense center - City center is easily accessible
  - Very sparse outside the center - Suburban public transportation …
  - Most of the destinations are outside the center - Every analogy limps …

*Rob Cantor

IMPROVING MEMORY PERFORMANCES

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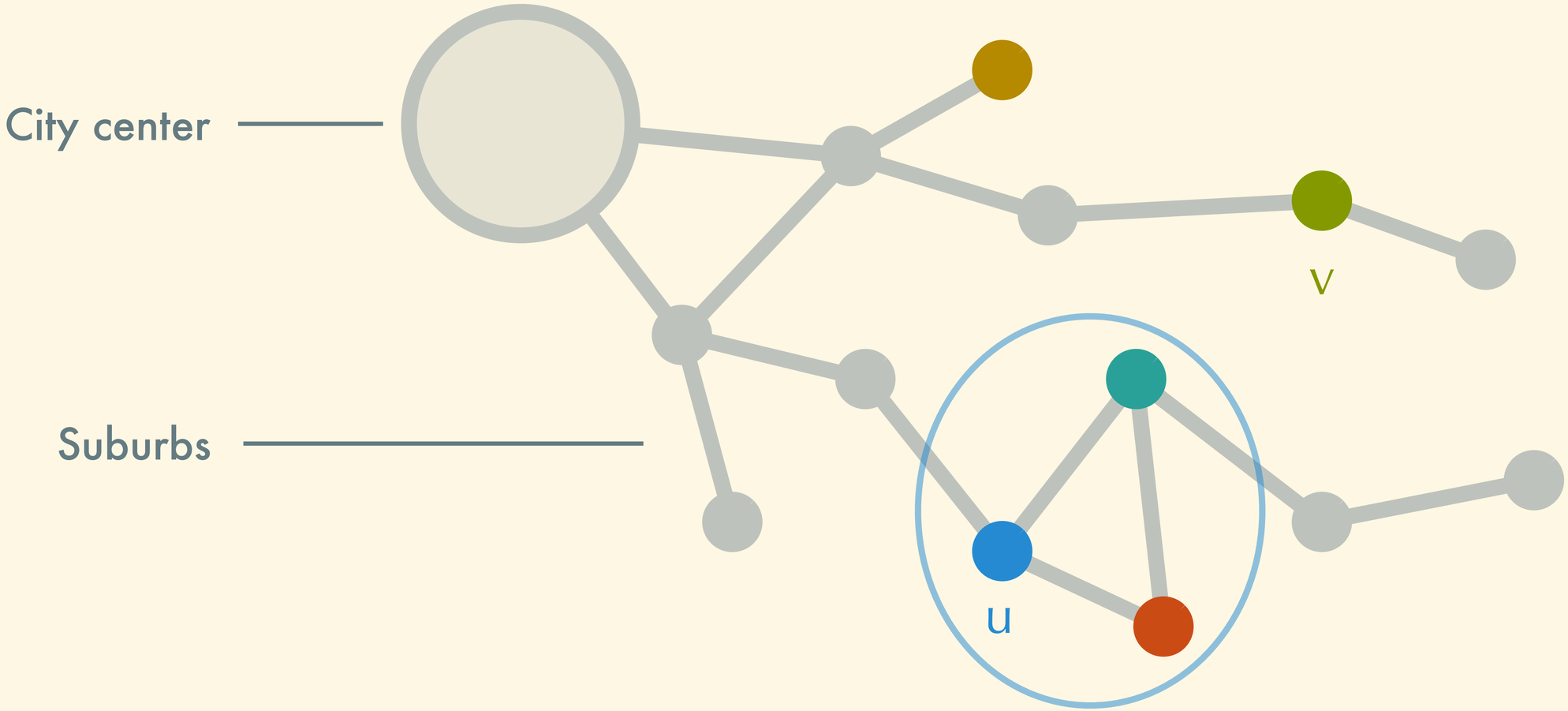

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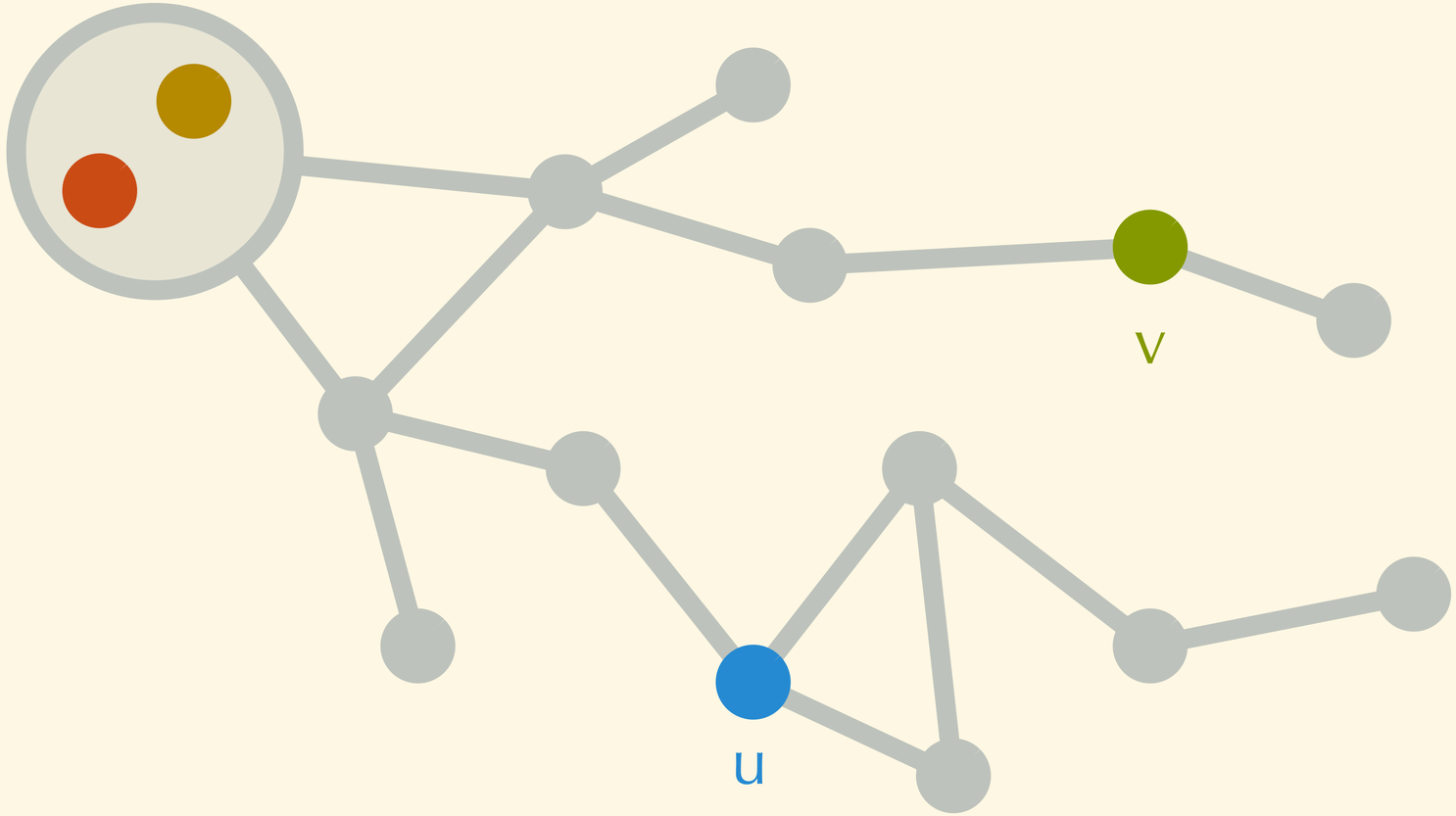

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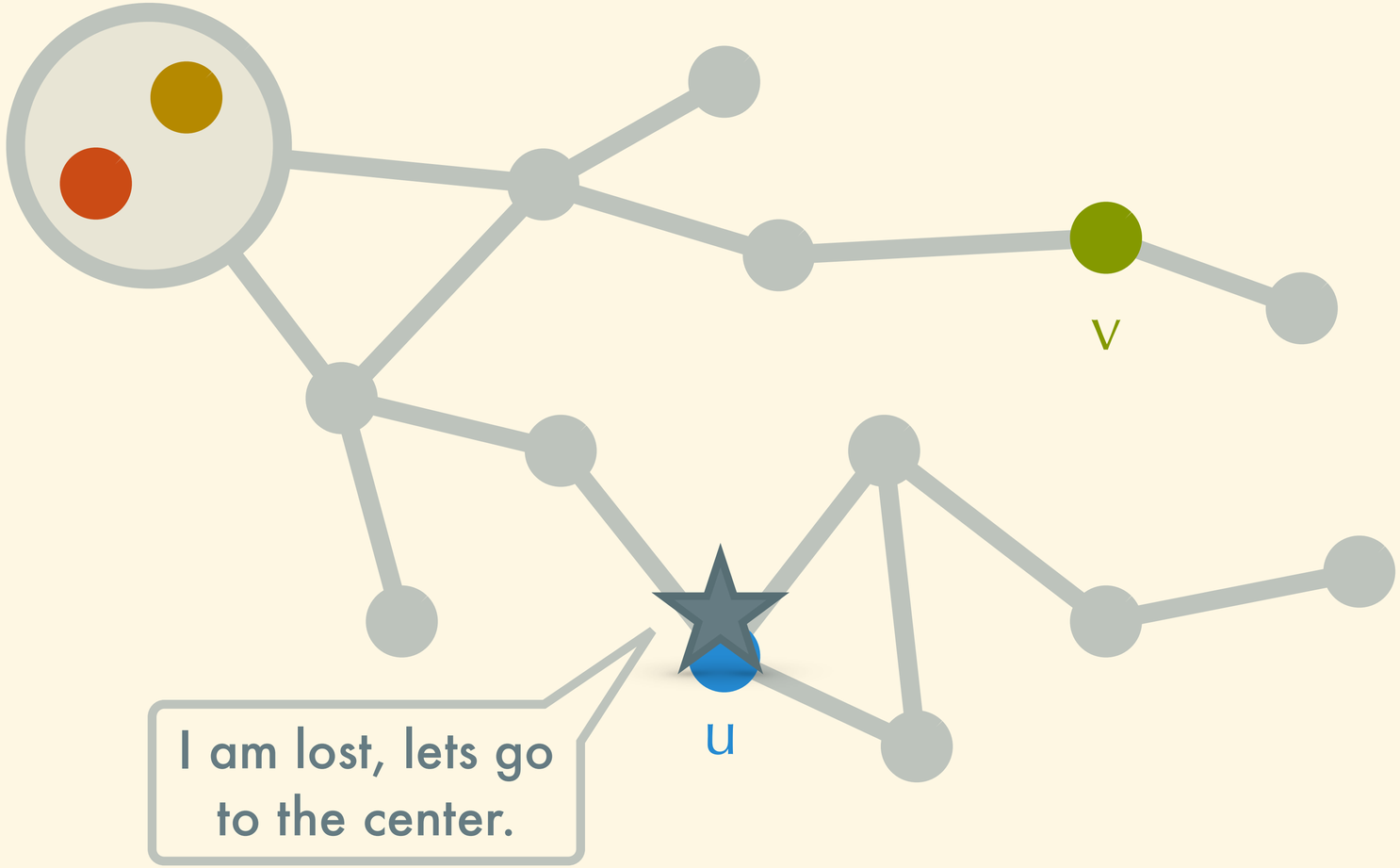

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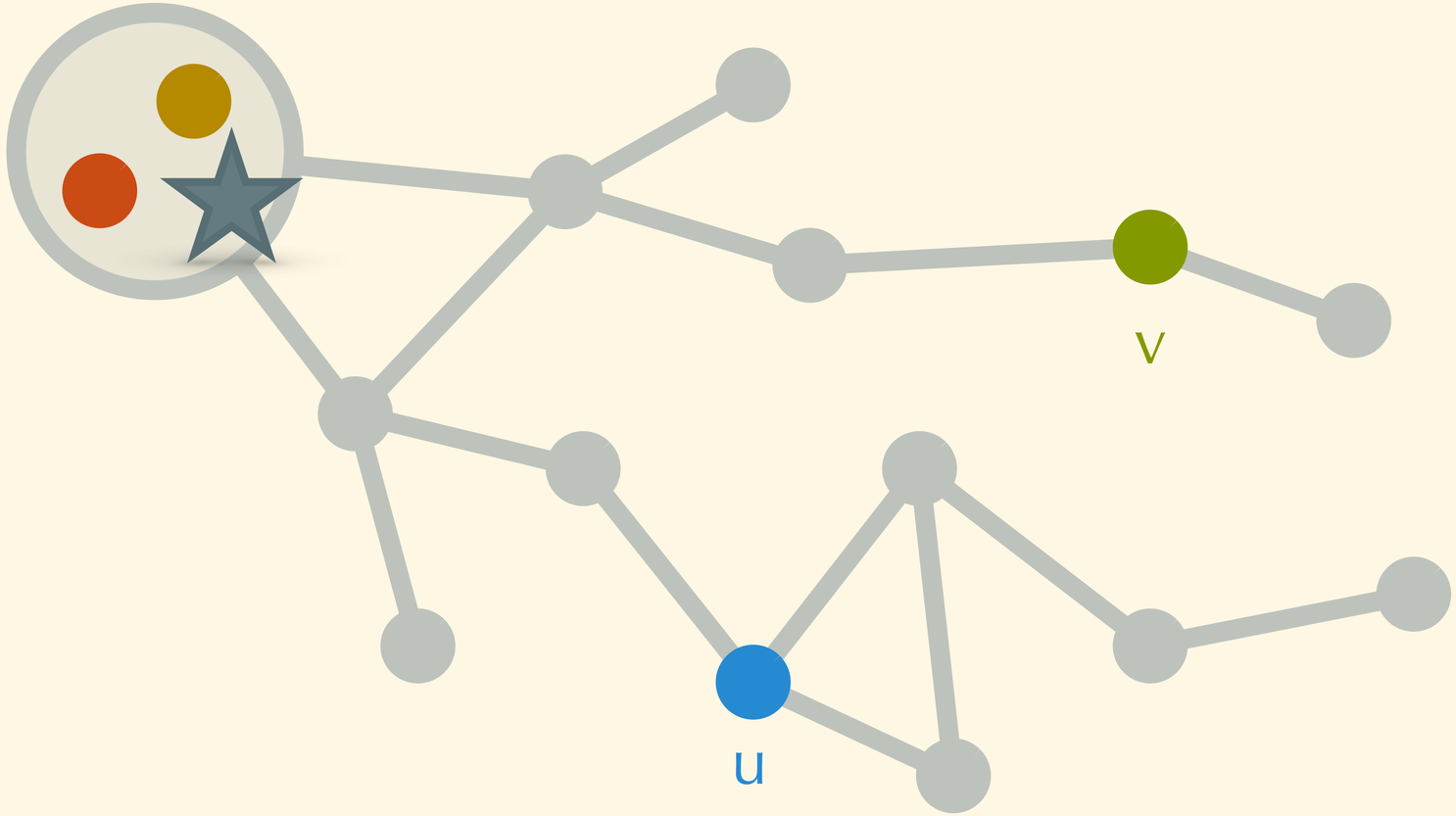

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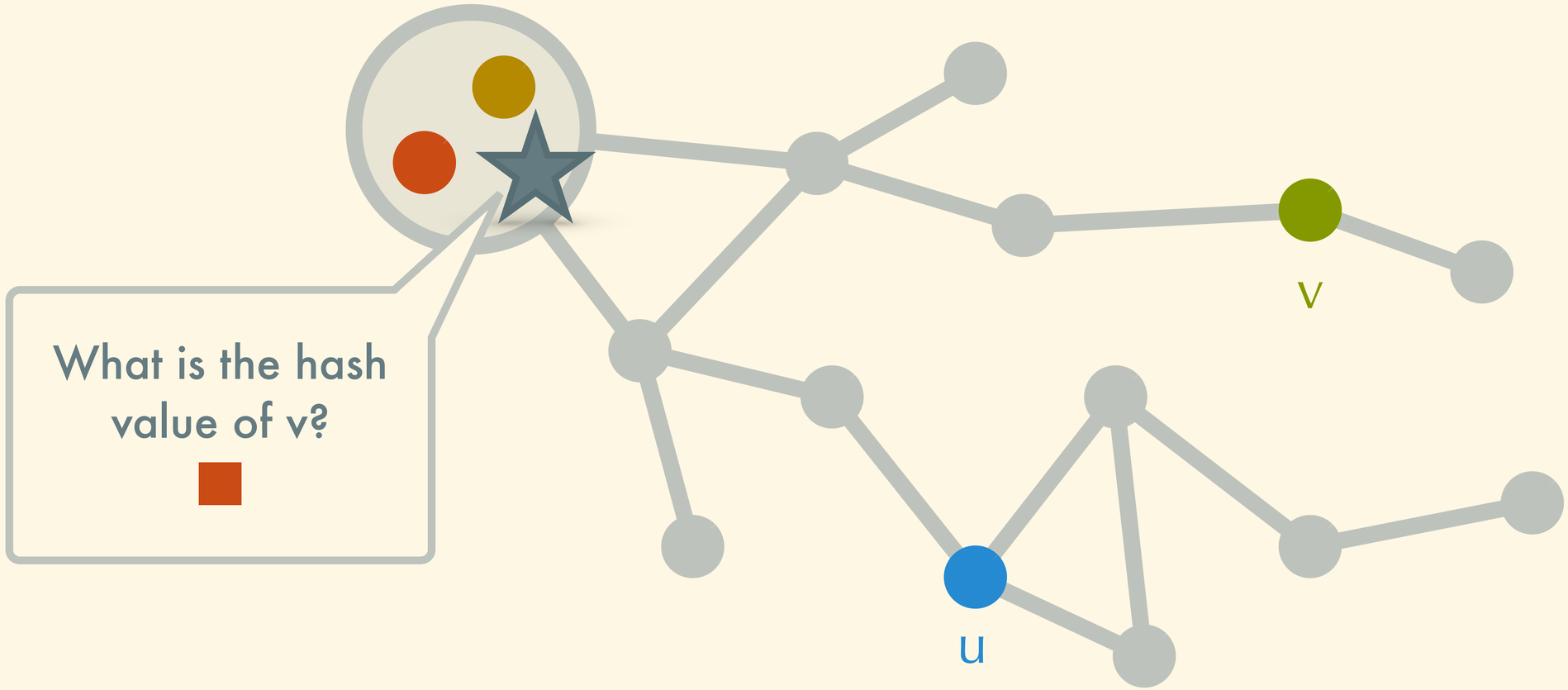

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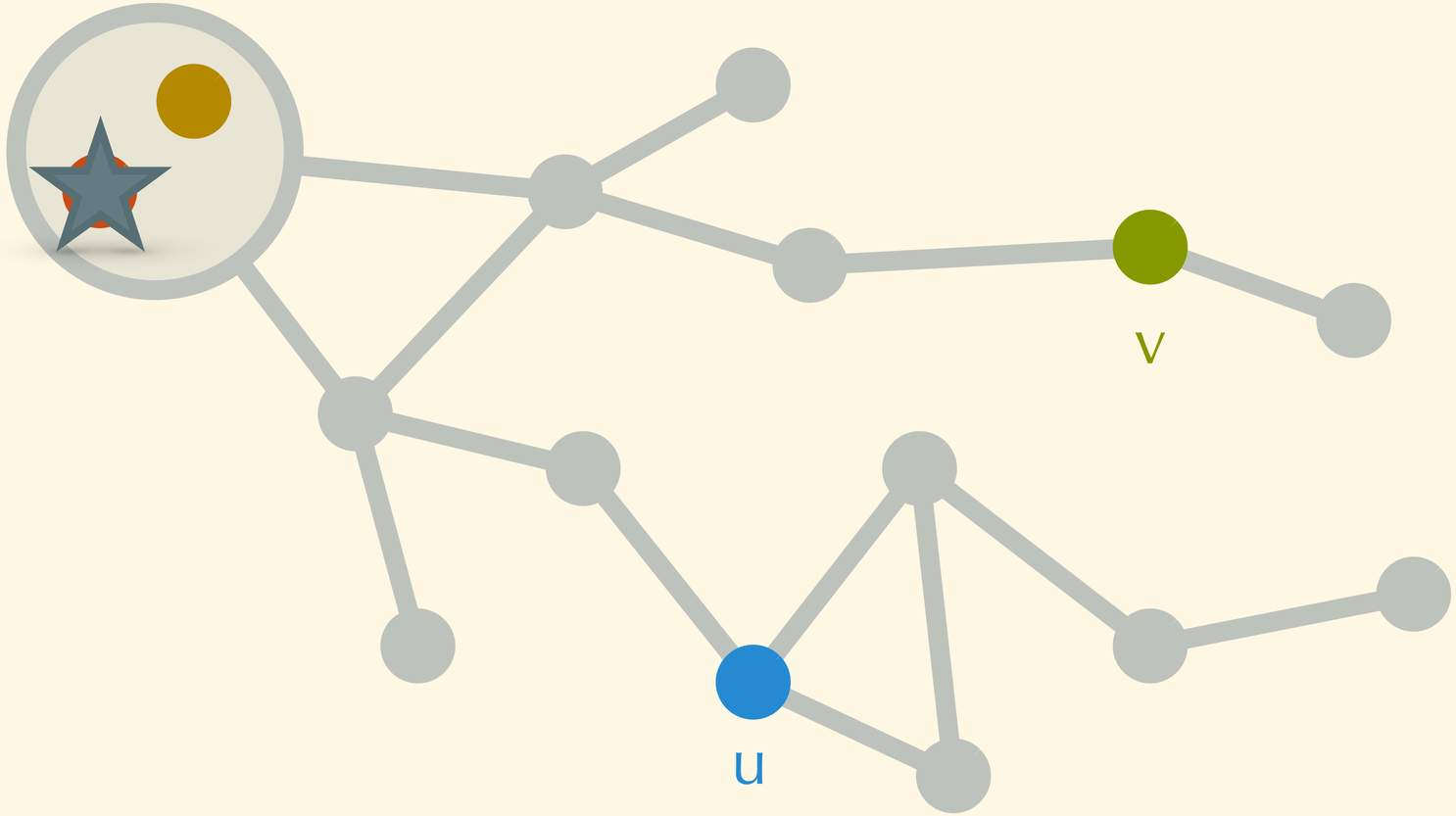

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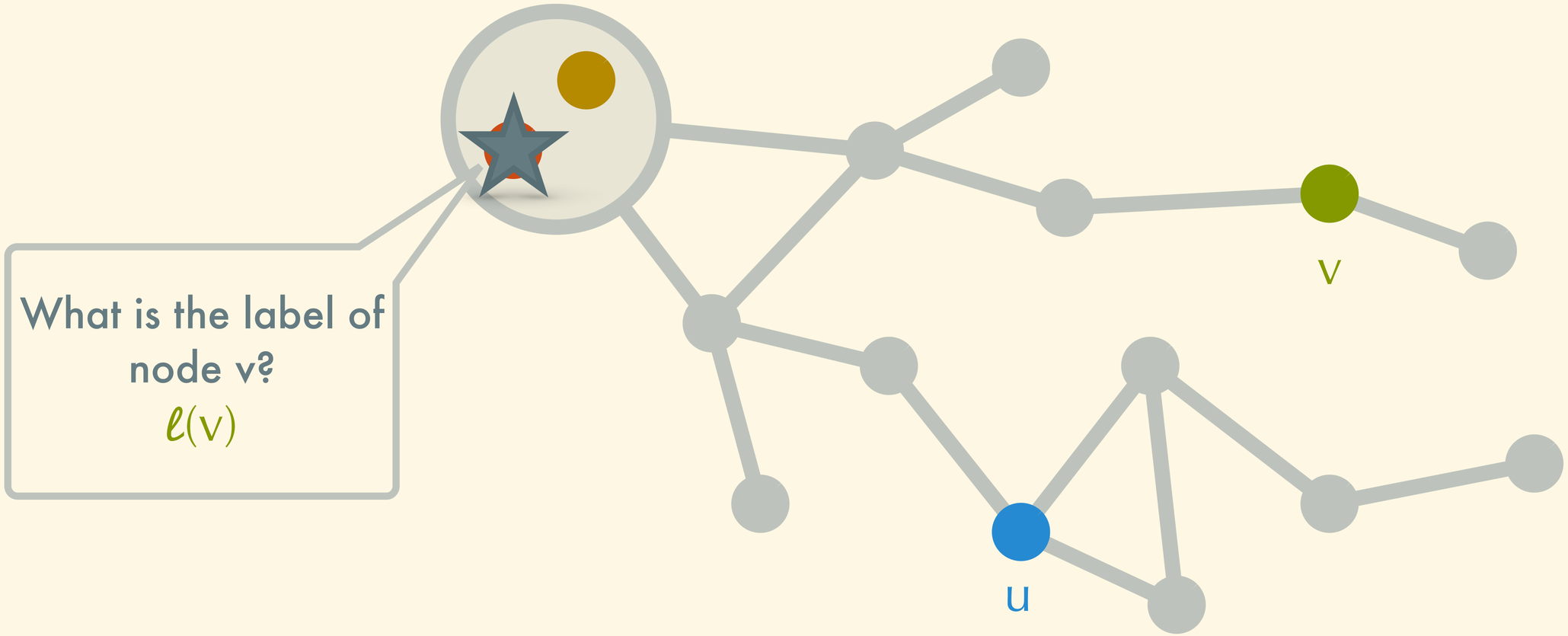

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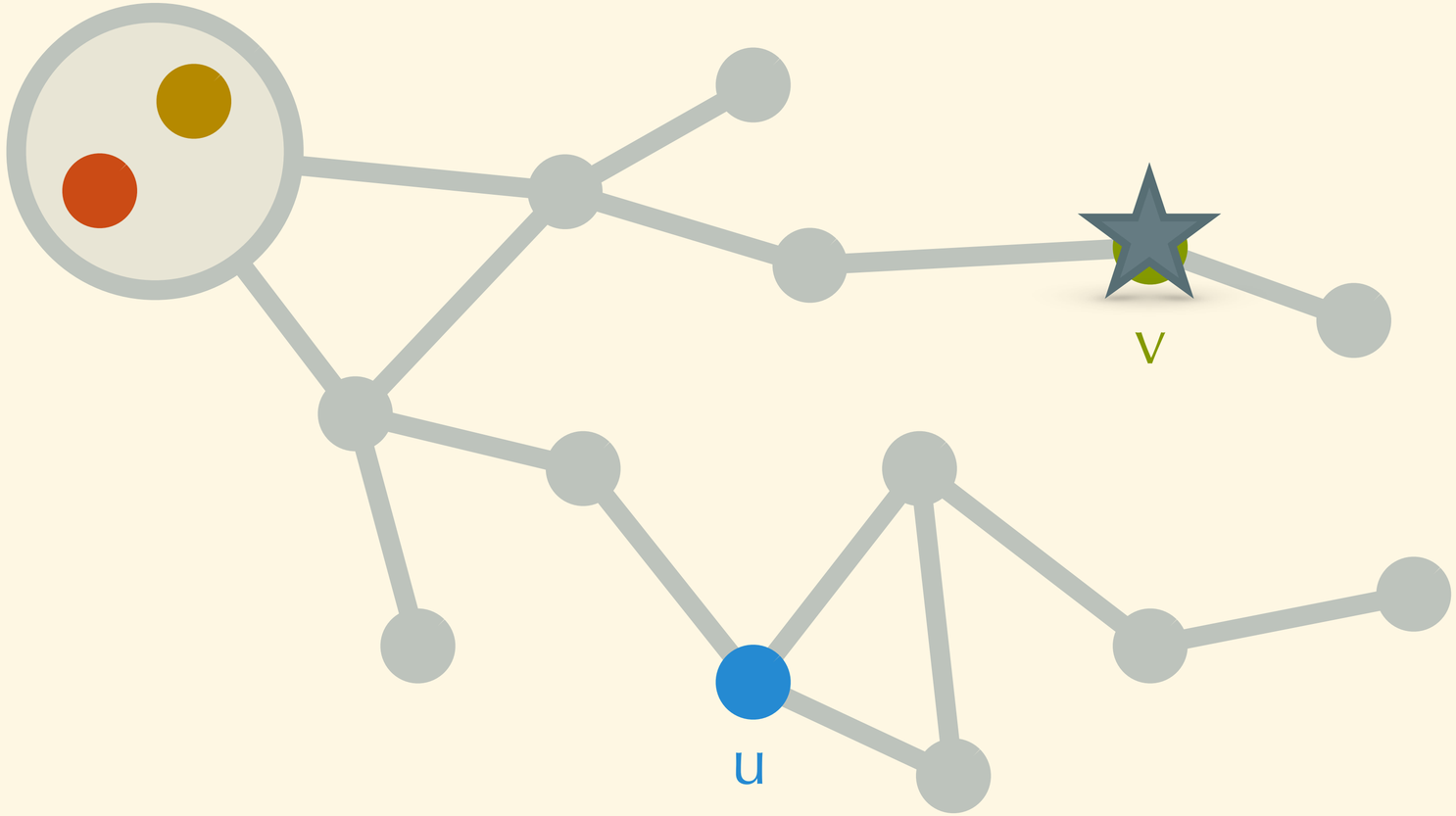

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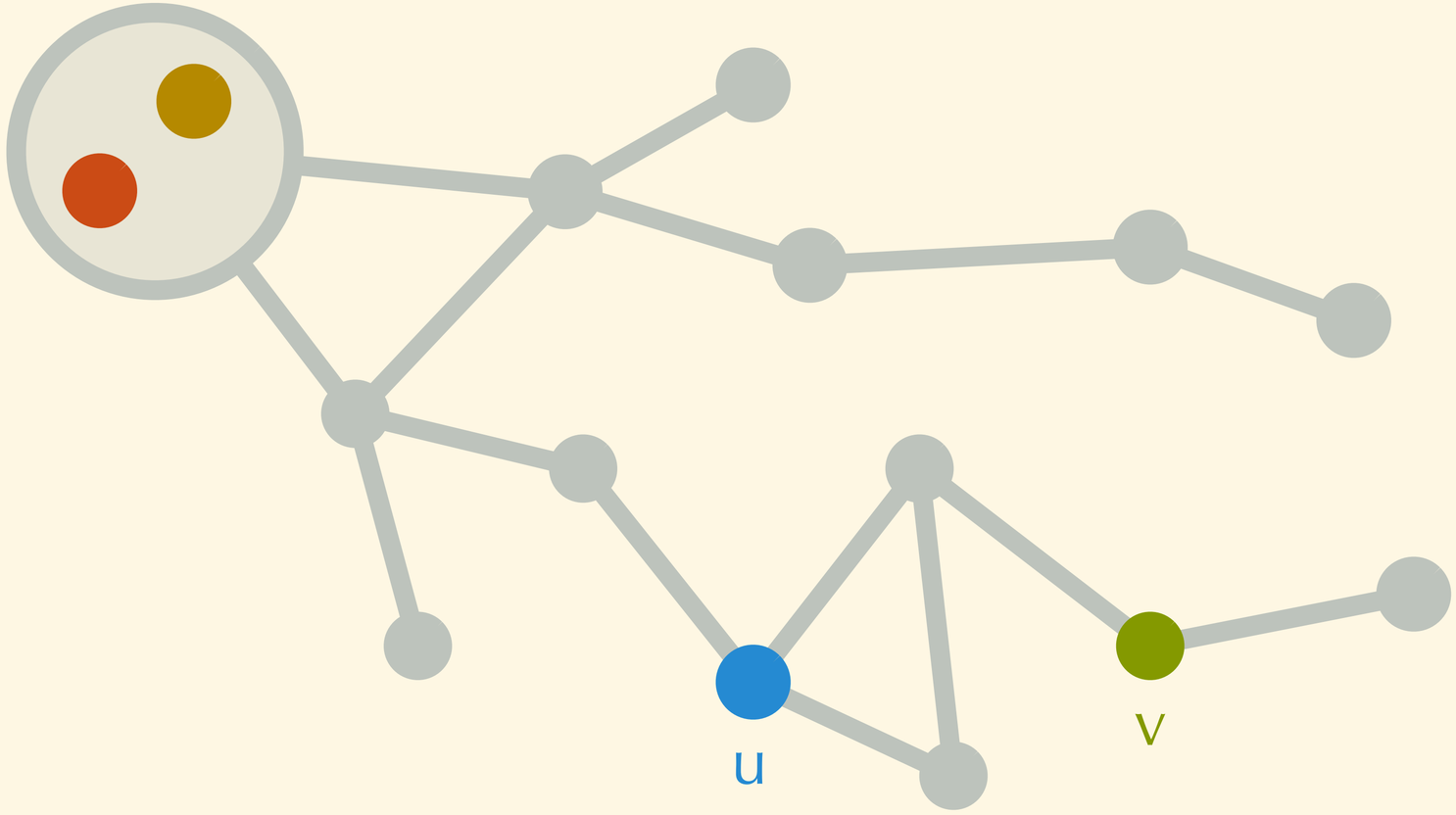

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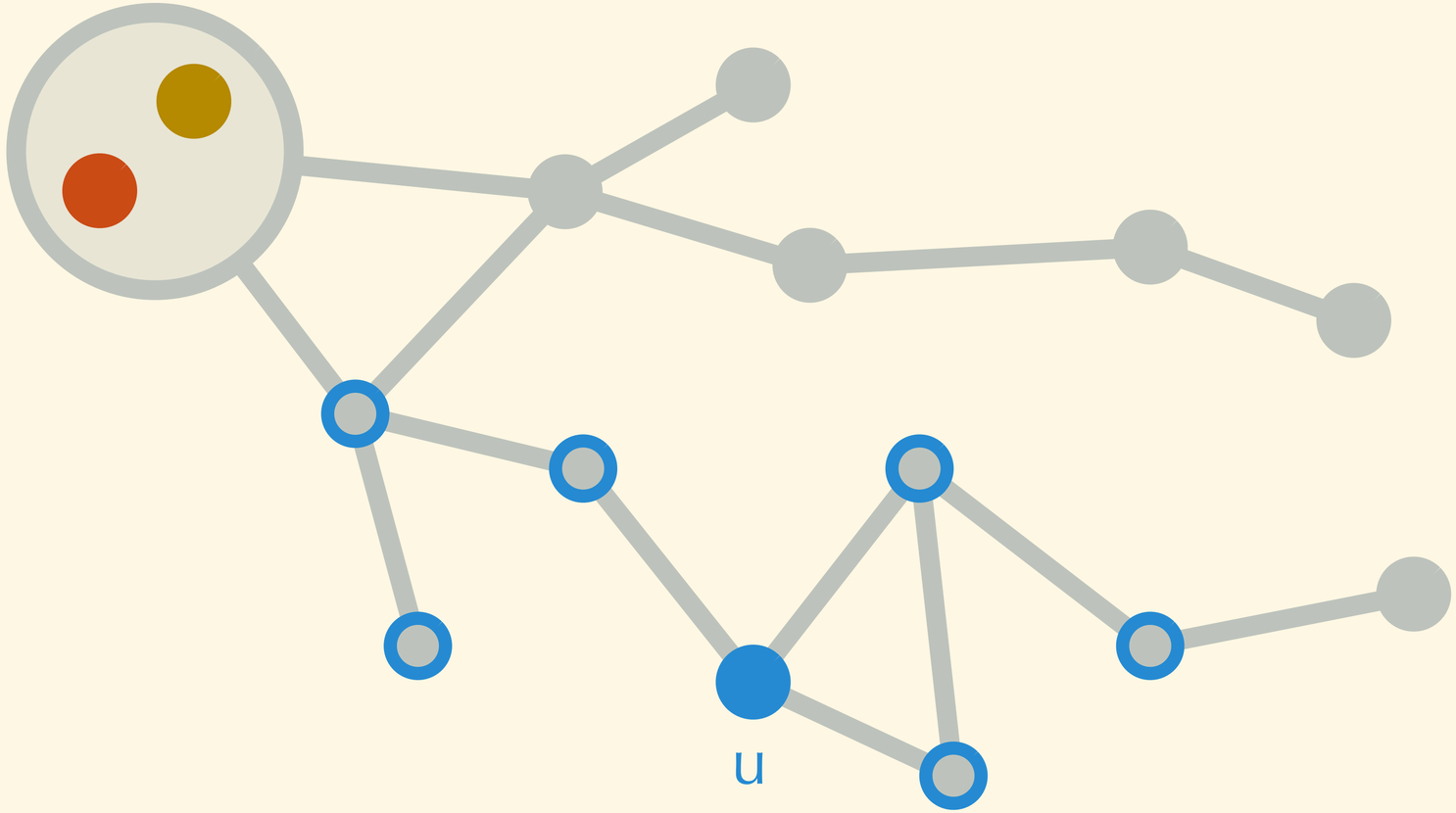


THEORETICAL RESULTS

Compared to older results for similar settings on RPLG

	Stretch	Memory	
		average	maximum
[GGHI'15]	5	$O(n^{1/(t-1)+t-3})$ $O(n^{1/110})$	$O(n^{1-1/(t-1)})$ $O(n^{1/11})$
Labeled [CSTW'12]	5	$O(n^{(t-2)/(2t-3)})$ $O(n^{1/12})$	
[TZLL'13]	≥ 6	$O(\sqrt{n})$	$O(n)$

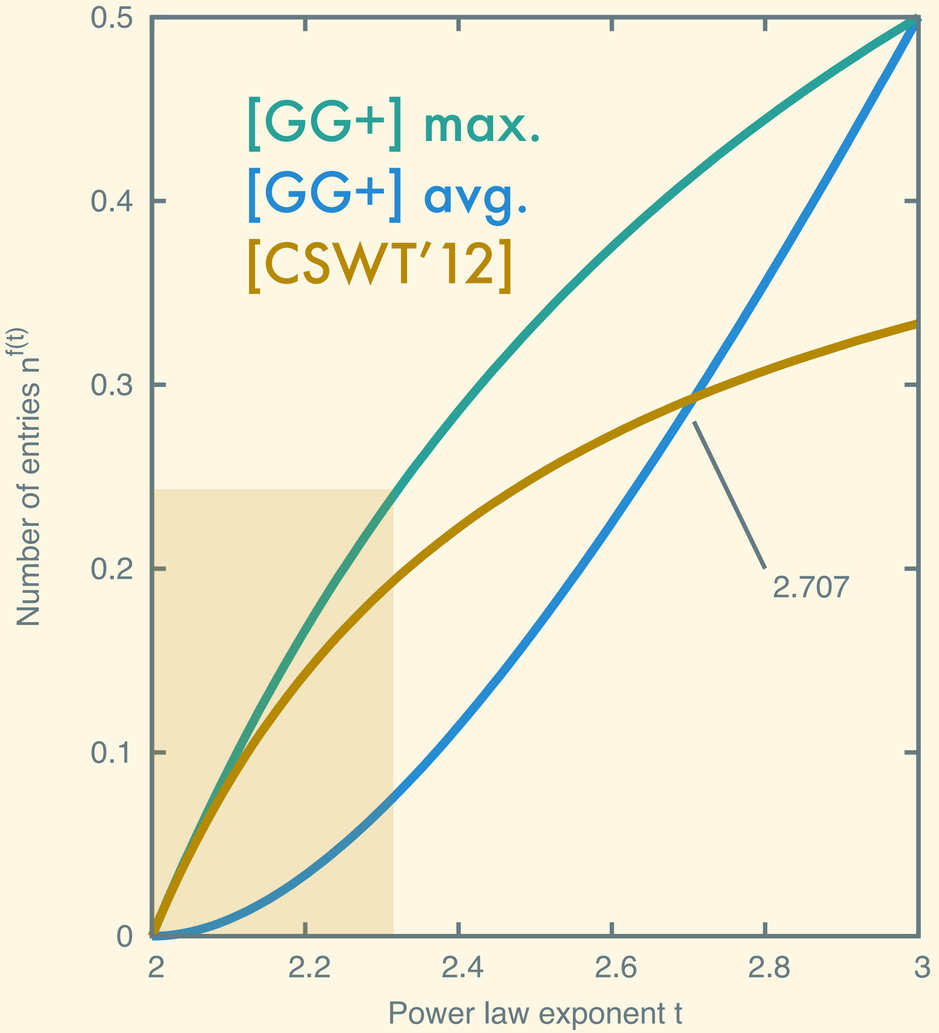
Upper bounds for $t = 2.1$

In depth [CSWT'12] vs. [GGHI'15]

Theoretical comparison for various exponential values

- when $t < 2.707$ [GGHI'15] avg. memory is smaller
- [CSTW'12]:
  - has a smaller theoretical max. memory
  - but is a labeled scheme!
- For small values of t, hidden constants may play an important role

What are the performances in practice?



EXPERIMENTAL RESULTS

For an RPLG with t=2.1

		avg stretch	memory	
			average	maximum
	[AGMNT'08]	1.56	396	1 143
Labeled	[CSTW'12]	1.30	55.2	580
	[TZLL'13]	1.24	404	1 877
	[GGHI'15]	1.75	6.47	228

EXPERIMENTAL RESULTS

For an AS-graph 16K nodes

		avg stretch	memory	
			average	maximum
	[AGMNT'08]	1.74	465	1 261
Labeled	[CSTW'12]	1.18	24	687
	[TZLL'13]	1.52	106	2 324
	[GGHI'15]	1.59	**4.05**	415

Future Works

- In sparse networks, for $q=1/2$, routing tables of size $\tilde{O}(n^q)$
  - communication cost is $\tilde{O}(n^{1+q})$
  - can that be done for any q?

- Labeled = Name-independent? (True for stretch 3)*
  - ie., name-independent routing with stretch $2k+1$ and memory $O(n^{1/k})$

- Very compact routing schemes for internet-like graphs:
  - "logarithmic memory is required for infinite scaling"

*Disclaimer: No prize is offered for solving this.

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