Net2Text: Query-Guided Summarization of Network Forwarding Behaviors

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net2text.ethz.ch

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ETH Zürich
Where is the traffic leaving in NEWY coming from?
Where is the traffic leaving NEWY coming from?

**Approach**

Look at entire forwarding state all the traffic statistics to identify important destinations to reroute

**Challenge**

From a wealth of low-level data, extract the high-level insights
Understanding how the network behaves, can take hours

Fast reaction is required
Customer experience depends on it

Networks get more and more complex
New peerings, more routers, etc.
What if you could simply ask the questions…

and automatically get an answer?
Where is the traffic...
Where is the traffic leaving in NEWY coming from?
Where is the traffic leaving in NEWY coming from?
The traffic enters mostly in PHIL and goes to Youtube and Netflix. Where is the traffic leaving in NEWY coming from?
Net2Text has four stages:
- parsing
- data retrieval
- summarization
- translation

Input: How is Google traffic to NEWY handled?

Workflow:
1. NL Parser
2. Summarization
3. Translation

Output: The Google traffic to NEWY enters in BOST...
Net2Text has four stages: parsing, data retrieval, summarization, translation

How is Google traffic to NEWY handled?

Workflow:
- NL Parser
- Summarization
- Translation

Output:
The Google traffic to NEWY enters in BOST...
The parser maps the operator’s query to the internal query language.

How is Google traffic to NEWY handled? → SELECT * FROM paths WHERE egress=NEWY AND dest=Google
Based on the query, Net2Text retrieves all relevant data

SELECT * FROM paths
WHERE egress=NEWY
AND dest=Google

The Google traffic to NEWY enters in BOST...
The database maintains
the forwarding state and traffic statistics
The database maintains the forwarding state and traffic statistics

<table>
<thead>
<tr>
<th>prefix</th>
<th>dest.</th>
<th>ingress</th>
<th>egress</th>
<th>avg. bw</th>
</tr>
</thead>
<tbody>
<tr>
<td>path 1 8.8.8.0/24</td>
<td>Google</td>
<td>BOST</td>
<td>NEWY</td>
<td>98.4 Mbps</td>
</tr>
<tr>
<td>path 2 46.14.0.0/16</td>
<td>Swisscom</td>
<td>BOST</td>
<td>NEWY</td>
<td>0.4 Mbps</td>
</tr>
<tr>
<td>path 3 81.63.0.0/17</td>
<td>Swisscom</td>
<td>ATLA</td>
<td>NEWY</td>
<td>25.0 Mbps</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>path n 8.8.178.0/24</td>
<td>Yahoo</td>
<td>ATLA</td>
<td>HOUS</td>
<td>1.0 Mbps</td>
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</table>
All the data is summarized by identifying a few clusters

How is Google traffic to NEWY handled?

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Input
Workflow
Output
All the data is summarized by identifying a few clusters

Input pertaining to Google traffic leaving in NEWY

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<tbody>
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<td>BOST</td>
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<td>path 2 8.8.4.0/24</td>
<td>BOST</td>
<td>T</td>
<td>0.4 Mbps</td>
</tr>
<tr>
<td>path 3 66.102.0.0/20</td>
<td>BOST</td>
<td>F</td>
<td>25.0 Mbps</td>
</tr>
<tr>
<td>path 4 35.184.0.0/19</td>
<td>HOUS</td>
<td>F</td>
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<td>...</td>
<td></td>
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Output

{BOST_i},
Each cluster represents a path specification
A summary consists of multiple path specifications

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Input pertaining to Google traffic leaving in NEWY

Output

\{BOST_i\},
All the data is summarized by identifying a few clusters

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Output

\[
\{BOST_i\}, \\
\{BOST_i, T_{sp}\}, \\
\{BOST_i, T_{sp}, ATL_w\}
\]
Path specifications are translated back to natural language

How is Google traffic to NEWY handled?

The Google traffic to NEWY enters in BOST...

$\{\text{BOST}_i\}$,
$\{\text{BOST}_i, \text{Tsp}\}$,
$\{\text{BOST}_i, \text{Tsp}, \text{ATL}_w\}$
The translation uses templates to obtain natural language from path specifications.

Input:

\{BOST_i\}, 
\{BOST_i, T_{sp}\}, 
\{BOST_i, T_{sp}, ATL_w\}

Output:

The Google traffic to NEWY enters in BOST...
Net2Text has four stages: parsing, data retrieval, summarization, translation.

Input: How is Google traffic to NEWY handled?

Workflow:
- NL Parser
- Summarization
- Translation

Output: The Google traffic to NEWY enters in BOST...
1. **Summarization**
   from question to succinct answer

2. **Scaling**
   summarizing fast

3. **Performance & operator interviews**
   summaries within a few seconds
1. **Summarization**
   from question to succinct answer

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   summarizing fast

3. **Performance & operator interviews**
   summaries within a few seconds
Finding a summary of the network-wide forwarding state is simple.

Traffic is being forwarded.
Finding a summary of the network-wide forwarding state is simple

Traffic from LOSA to 35.184.0.0/19, which is owned by Google, is leaving the network in CHIC and takes the path SUNV, DENV, KSCY, INDI to CHIC.
Coverage
amount of data described by the summary

Explainability
amount of detail provided by the summary
Traffic is being forwarded.

Coverage

Explainability
Traffic from LOSA to 35.184.0.0/19, which is owned by Google, ...

Coverage

Explainability
Coverage vs. Explainability

better
Summarization is an optimization problem guided by the summary score

Score

Weighted sum of the amount of traffic covered by each path specification in the summary.
Summarization is an optimization problem guided by the summary score.

Score

- Coverage

Weighted sum of the amount of traffic covered by each path specification in the summary.
Summarization is an optimization problem guided by the summary score.

**Score**

- **Explainability**
  weights based on level of detail of the path specification

- **Weighted sum** of the amount of traffic covered by each path specification in the summary.
Summarization is an optimization problem guided by the summary score.

<table>
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<tr>
<td>Goal</td>
<td>Find path specifications that maximize the score.</td>
</tr>
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</table>
all the data
in all details
Summarization is an optimization problem guided by the summary score and a size restriction.

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</tr>
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<td>Goal</td>
<td>Find $k$ path specifications each of size at most $t$ that maximize the score.</td>
</tr>
</tbody>
</table>
$k = 3, t = 3$

$\emptyset, \emptyset, \emptyset$

$\bigcirc$
The search space is exponential in the number of path specifications and feature values.
Due to the size of the search space, exhaustive exploration is not feasible
1 Summarization
   from question to succinct answer

2 Scaling
   summarizing quickly

3 Performance & operator interviews
   summaries within a few seconds
Net2Text relies on two optimizations

Optimization 1
- Approximation
  - Reduce the search space

Optimization 2
- Sampling
  - Reduce the input data
Optimization 1

Approximation

Reduce the search space

Sampling
The search space contains two types of edges: **blue edges** that increase coverage.
The search space contains two types of edges:

**red edges** that increase explainability

Maximal explainability

Maximal coverage
Net2Text reduces the search space to solutions that balance coverage and explainability.
Net2Text reduces the search space to solutions that balance coverage and explainability.

Balanced coverage and explainability
Net2Text reduces the search space to solutions that balance coverage and explainability.

Graph has a monotonicity property.
The child’s score is always higher.

Net2Text greedily explores the graph.
Always follow most promising path.

Solution is not far off from best solution.
Guaranteed lower bound on the score.
Approximation

Optimization 2

Sampling

Reduce the input data
Network traffic is highly skewed across multiple levels

**Level 1**  Traffic distribution
Few destinations carry most of the traffic

**Level 2**  Routing and network topology
Repetitive forwarding patterns

**Insight**  Network traffic is repetitive and redundant
Net2Text uses redundancy in the data to speed up summarization by sampling

<table>
<thead>
<tr>
<th>Problem</th>
<th>Net2Text iterates over all entries at least once</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insight</td>
<td>Summary is resilient to loss of redundant information</td>
</tr>
<tr>
<td>Solution</td>
<td>Reduce input data by sampling</td>
</tr>
</tbody>
</table>
1. Summarization
   from question to succinct answer

2. Scaling
   summarizing fast

3. Performance & operator interviews
   summaries within a few seconds
Net2Text needs to be quick and applicable

Aspect 1
- Performance
- End-to-end timing

Aspect 2
- Applicability
- Operator interviews
Aspect 1

Performance

End-to-end timing

Applicability
Pushing Net2Text to its limits by summarizing the entire forwarding state

**Question**

How is traffic being forwarded?

**Setup**

ATT North America from Topology Zoo
25 nodes, 10 of them egresses

Full routing tables (~650k prefixes)

**Four features**

- ingress
- egress
- destination
- shortest path
Score
w.r.t. no sampling

Net2Text
no sampling

95
Net2Text finds good summaries within seconds thanks to sampling
Baseline is slightly faster than Net2Text, but not as resilient to sampling.
Only sampling higher than $1/5k$ has a significant effect on the score.
Net2Text needs to be quick and applicable

- Performance
- Applicability
- Operator interviews
We asked various operators about Net2Text, they found it useful

**Assistants**  Operators see value of assistants in their daily tasks  Support in all time consuming tasks

**NL I/O**  NL is useful, especially for less technical people  Operators don’t mind to use query languages

**Questions**  Supported questions are relevant  Especially “Where is the traffic coming from?”
Net2Text assists network operators by summarizing the forwarding state

- Net2Text answers questions in natural language with a succinct summary in natural language
- Net2Text presents a summary that balances coverage and explainability
- Net2Text responds in a timely manner and the supported queries are relevant
Net2Text
Query-Guided Network Captioning

net2text.ethz.ch

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