Thwarting Bobby Droptables: Adapting a TF-IDF HTTP Classifier to Embedded Hardware

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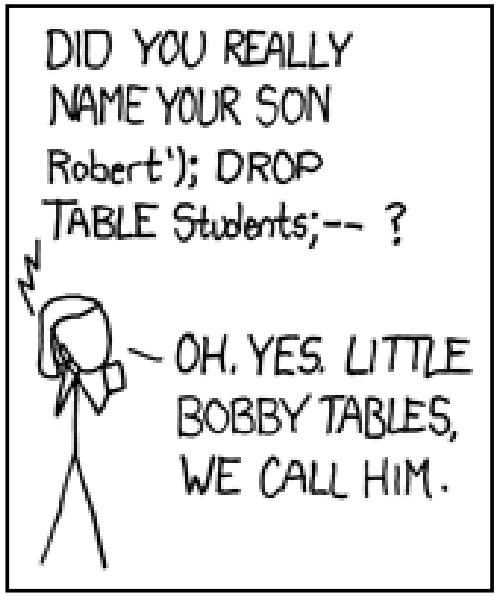
Network Security is Challenging

- Mixed requirements in server security
  - Provide flexible web services
  - Do so on top of existing standards
  - Thwart malicious behavior
- HTTP is conduit for web traffic
  - Simple, plain-text formatting
  - Gateway to databases, files, executables
- Malicious users also use these interfaces
  - Query a DB, invoke commands
  - Obfuscate commands, game network filters
- Can we embed more intelligent filtering in the network?



From xkcd, Randall Munroe
http://xkcd.com/327

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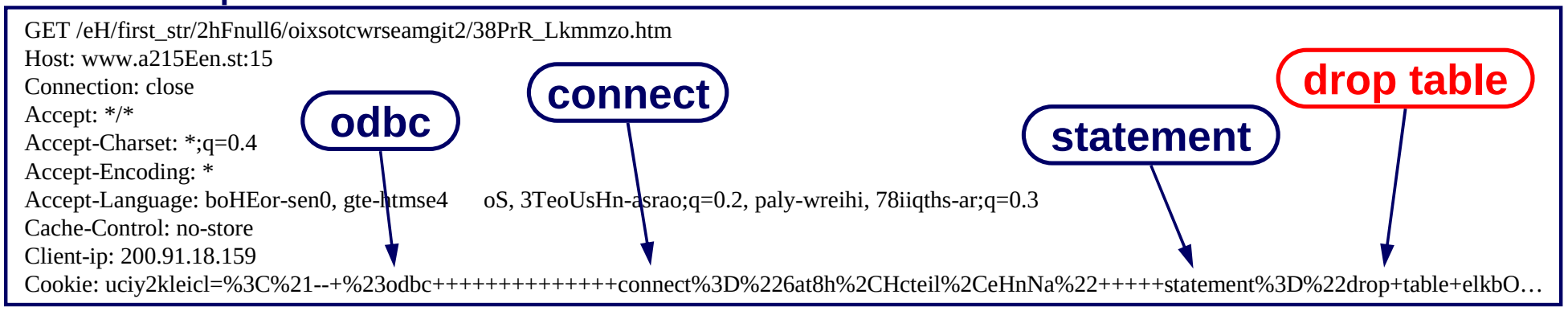
Overview

- LLNL work on HTTP attack classification
- Can this be converted to run on embedded network hardware?
  - Tilera or FPGAs: limited memory, operate in streaming manner
  - Need to convert 160MB dictionary to ~128 KB
- Our approach
  - Hypothesis: number of terms more useful than exact probabilities
  - Compress dataset via truncation and hashing tricks
- Status
  - Implemented core hardware design for FPGAs
  - Porting C version to Tilera

ECML/PKDD 2007 Discovery Challenge

- HTTP Traffic Classification
  - Apply machine learning to identify malicious activity in HTTP
- Hand-labeled datasets of HTTP flows
  - Training: 50K inputs, 30% attacks
  - Competition: 70K inputs, 40% attacks
  - 7 Attack Types XSS, SQL/LDAP/XPATH injection, path traversal, command execution, and SSI

Flow Example



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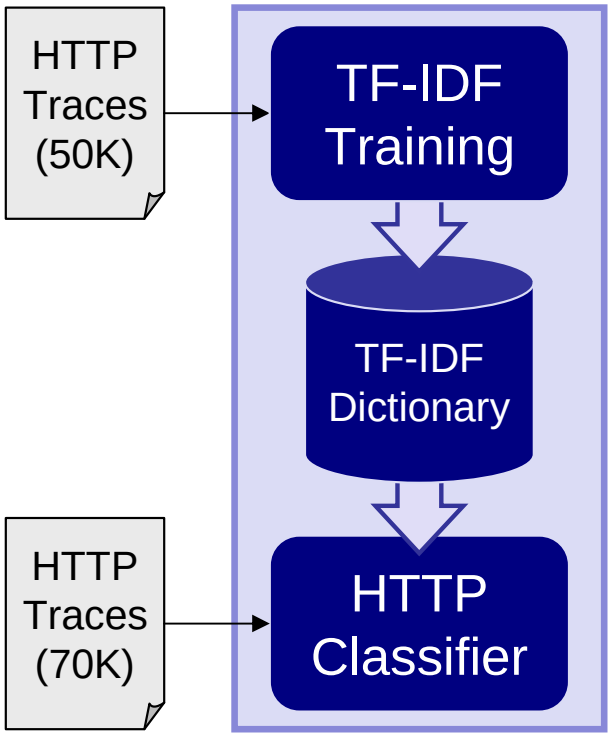
LLNL Work Achieved 99% Accuracy

- Brian Gallagher and Tina Eliassi-Rad
- Vector approach
  - Tokenize input
  - Assign weights to tokens via TF-IDF
  - Cosine similarity for vector comparison
- Relies on a data dictionary
  - Generate term statistics during training
  - Reference statistics at runtime



Top 3 SSI Classifier Terms

Term	IDF	Weight
odbc	2.079	0.0134
statement	2.079	0.0134
--	0.988	0.0126

Top 3 OS Commanding Classifier Terms

Term	IDF	Weight
..	1.386	0.0057
dir	2.079	0.0053
/c	2.079	0.0051

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Equations

- Term-Frequency, Inverse Document Frequency
  - TF: How often does each term appear in an attack?
  - IDF: How specific is the term to an attack?

$$tfidf(t,d) = \underbrace{\frac{count(t,d)}{\sum_{v \in d} count(v,d)}}_{Term\ Frequency} \cdot \underbrace{\log \frac{|D|}{|\{d_j : t \in d_j\}|}}_{Inverse\ Document\ Frequency}$$

- Cosine Similarity
  - Vector dot product to estimate angle between input and attack

$$\text{sim}_{\cos}(a,R) = \frac{\vec{a} \cdot \vec{R}}{\|\vec{a}\| \cdot \|\vec{R}\|} = \frac{\sum_{t \in a \cap R} tfidf(t,a) \cdot tfidf(t,R)}{\sqrt{\sum_{t \in a} tfidf(t,a)^2} \cdot \sqrt{\sum_{t \in R} tfidf(t,R)^2}}$$

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Equations for Programmers

$$score[classifier] = \frac{\sum_{t \in a \cap R} \frac{count[t]}{\#\,input\ terms} \cdot idf[t] \cdot ClassLabelTfidf[classifier][t]}{\sqrt{\sum_{t \in a} \left(\frac{count[t]}{\#\,input\ terms} \cdot idf[t]\right)^2} \cdot DocMagnitude[classifier]}$$

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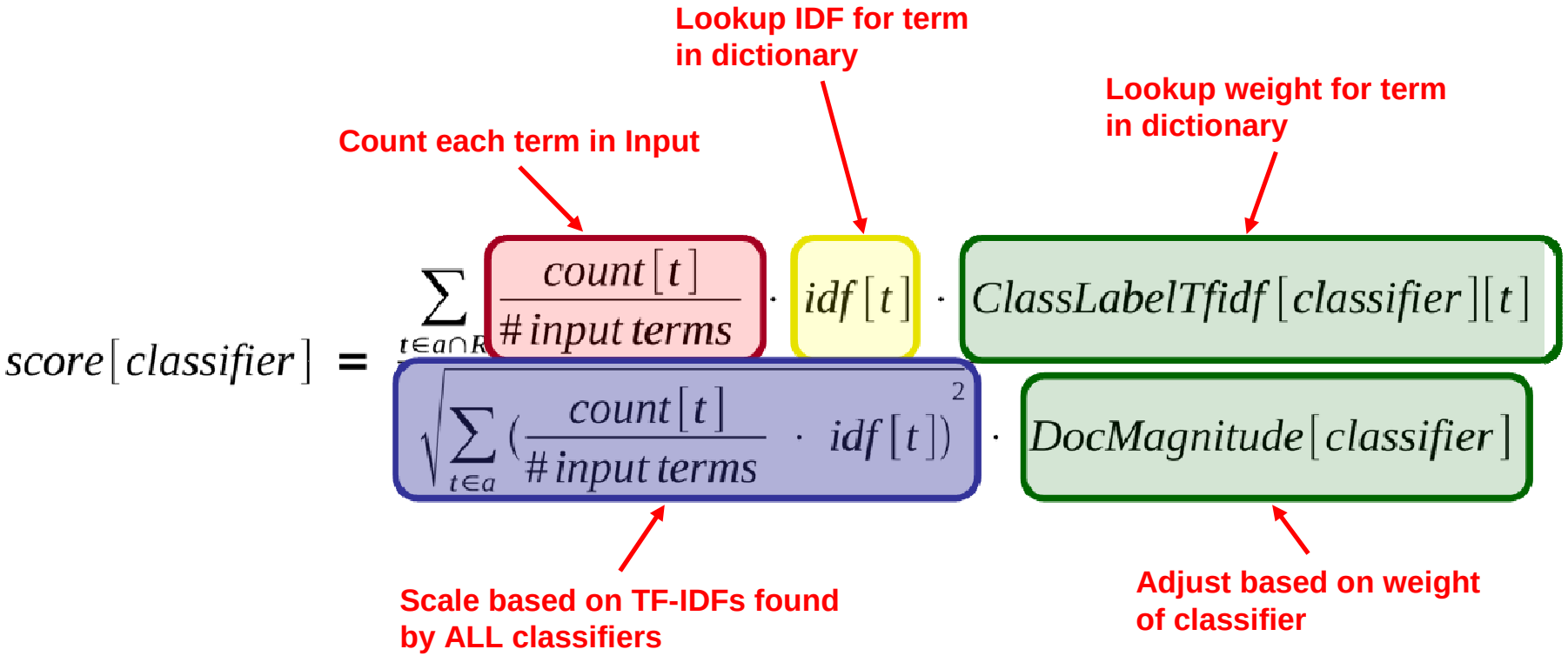
Equations for Programmers



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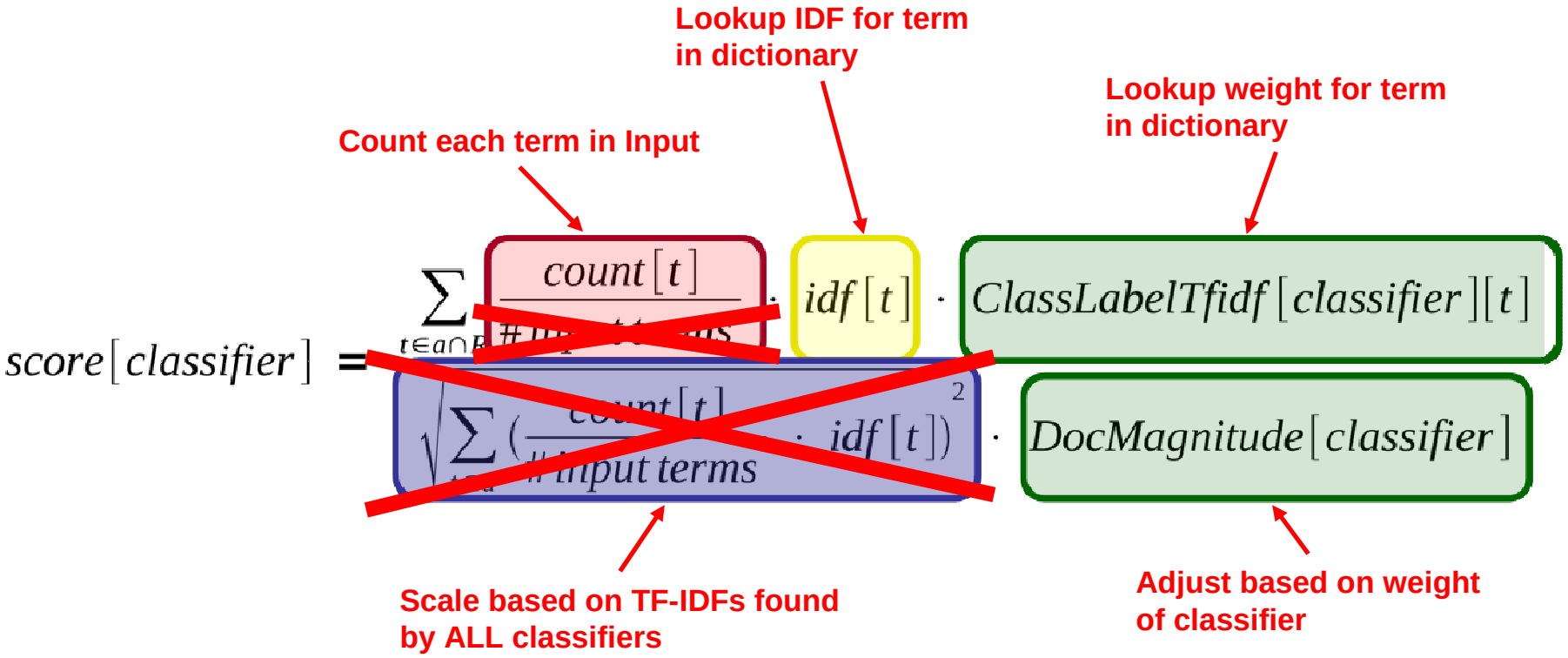
Equations for Programmers



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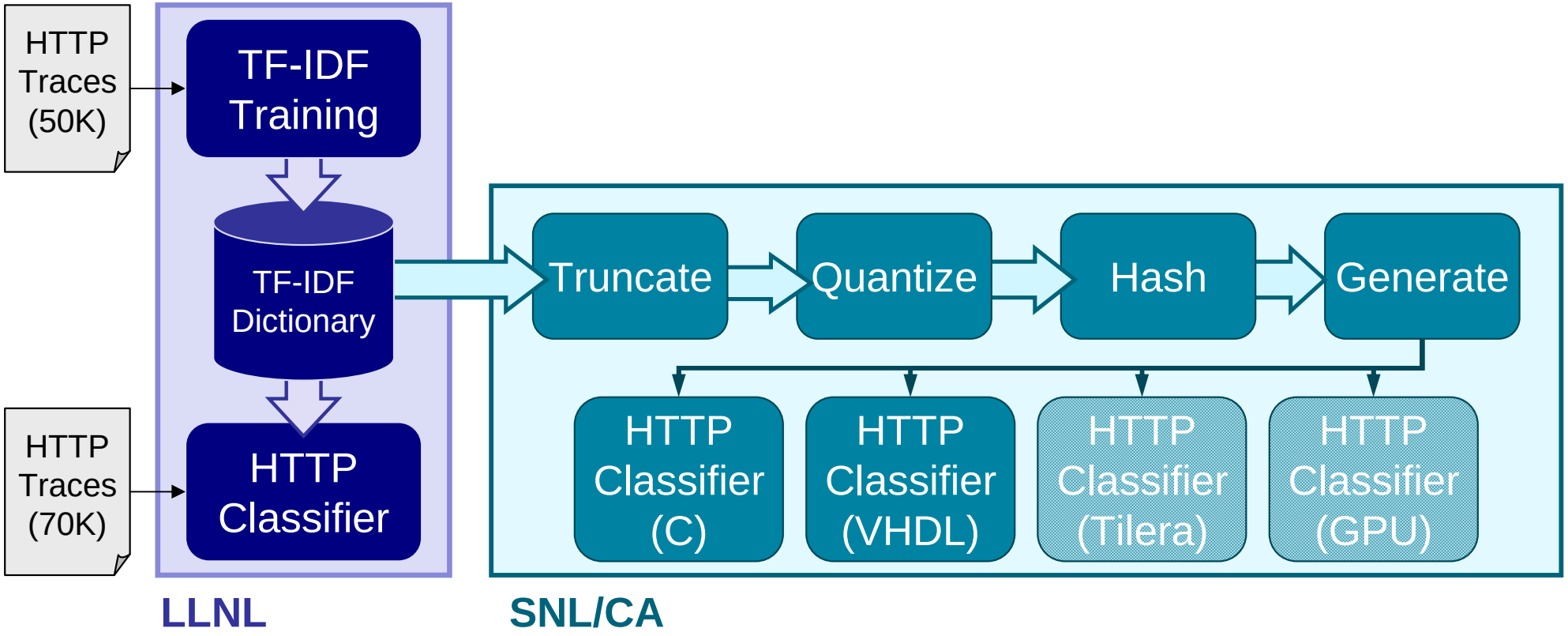
The Path to Embedded Hardware



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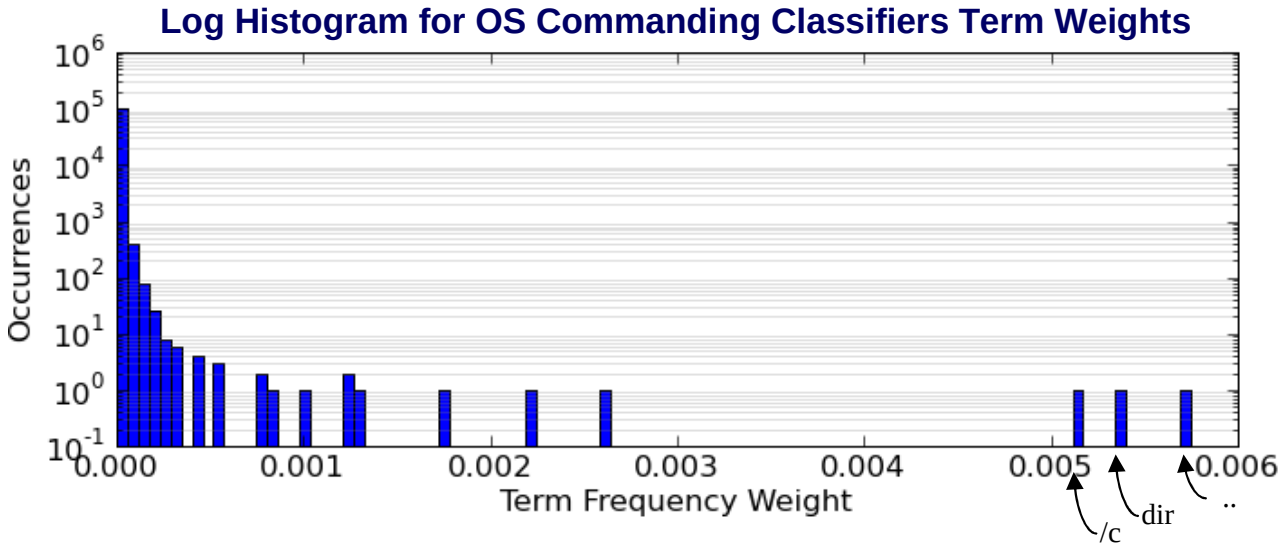
Dictionary Observations

- Many terms in the dictionary
  - 1.8M terms (46MB text, 128MB data)
  - Many terms are junk (“rv:0.7.8”), but they also get very low weight
- Data values are not very diverse
  - Total unique values is < 2% of population
  - Eg: OSC Classifier has 102K terms, but only *415* unique weights



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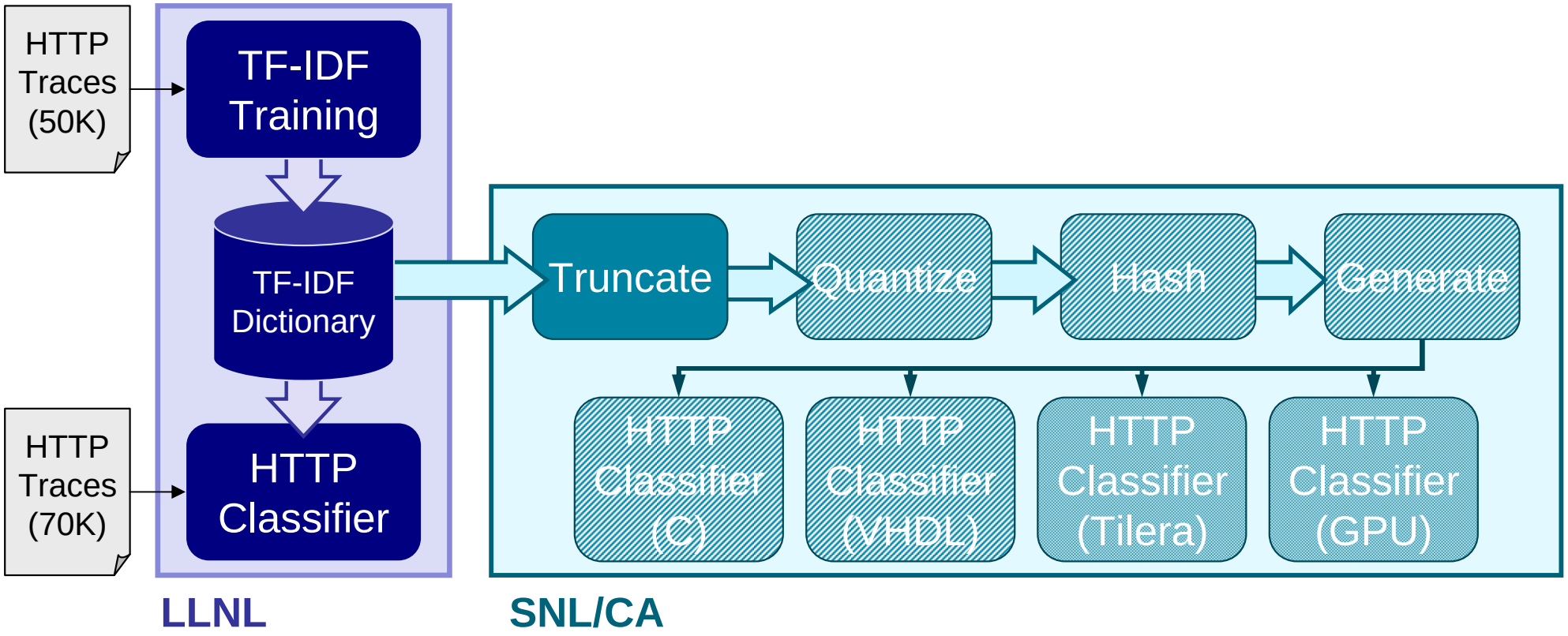

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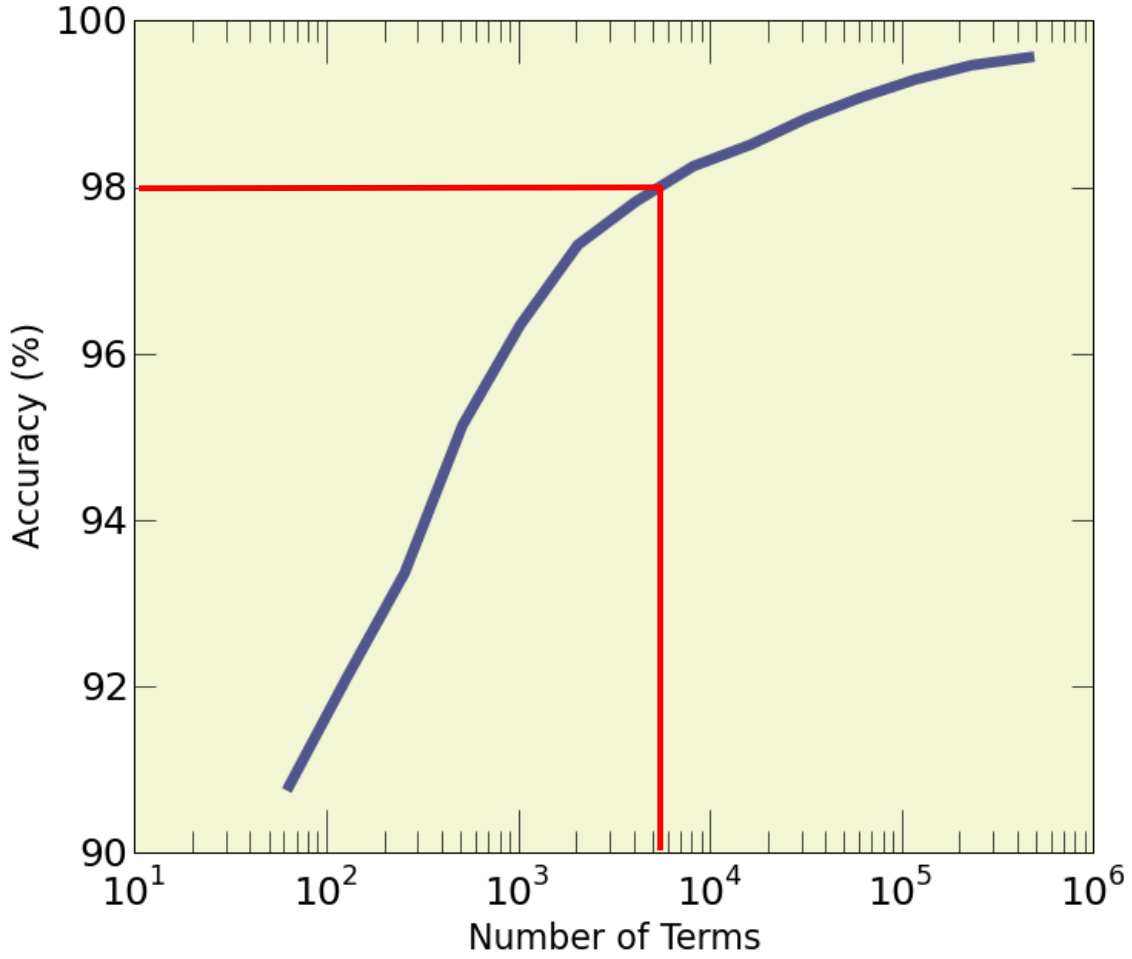
Easy: Truncate the Dictionary



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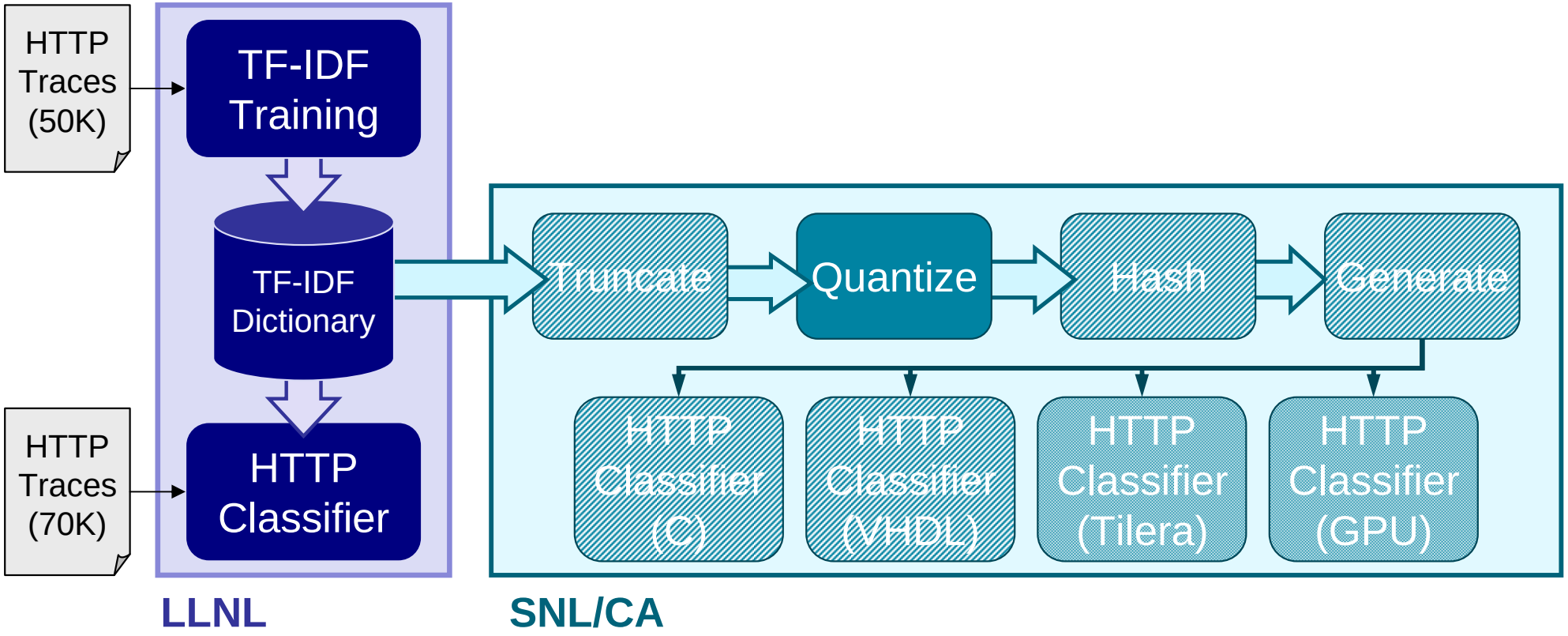

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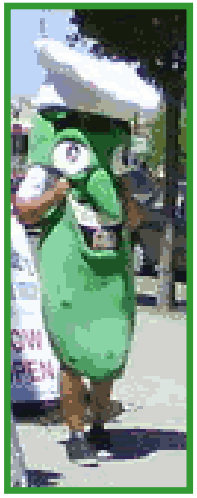
Quantize Dictionary Data Values

- How accurate do data values in dictionary need to be?
- Does IDF("ODBC") = 0.500001 give more accurate results than..
  - 0.500002? 0.488886? 0.03?
- Experiment:
  - Reduce unique data values in dictionary, measure accuracy impact


256 Colors


64 Colors


16 Colors


2 Colors

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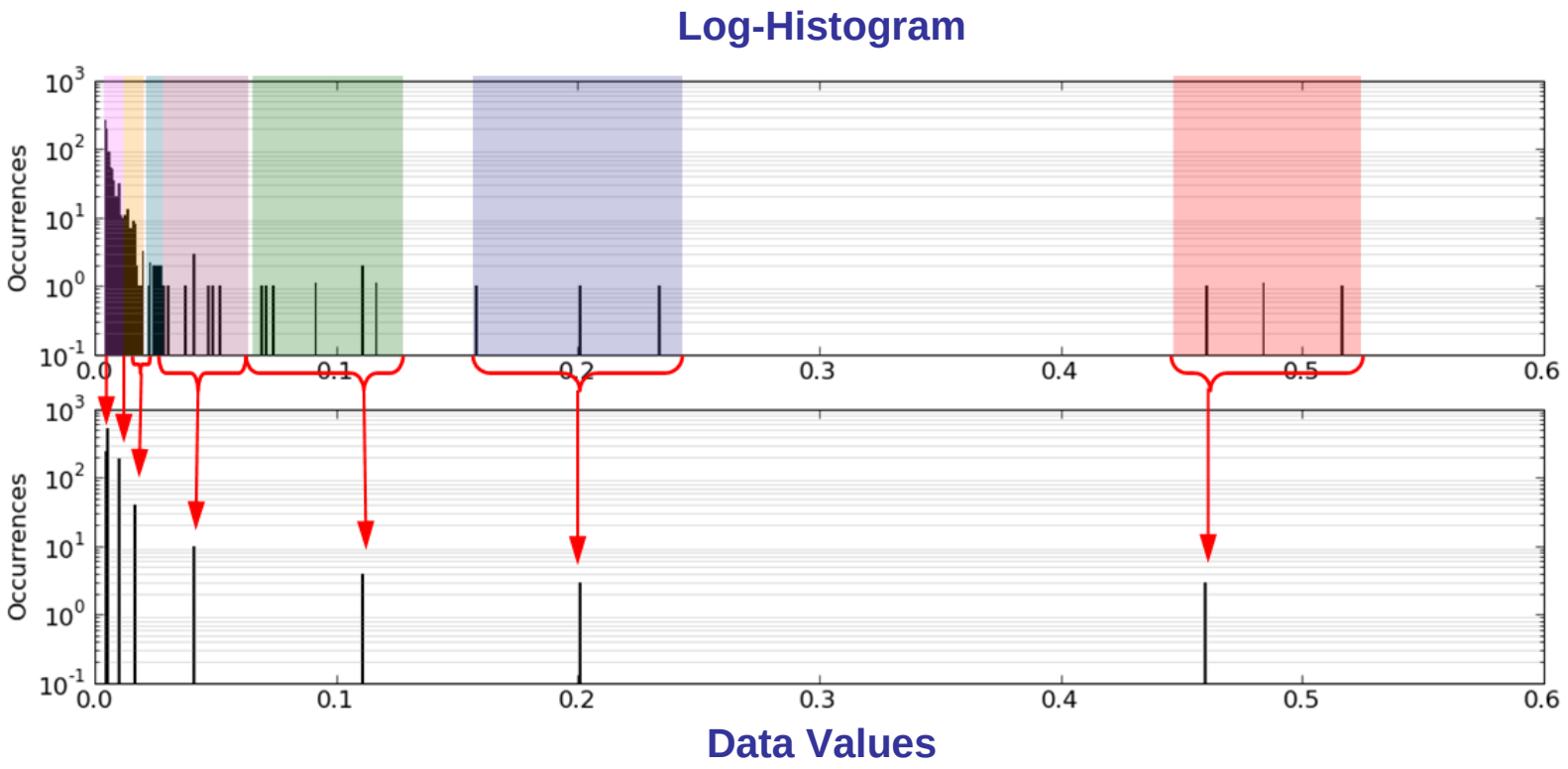
Re-Quantizing Data



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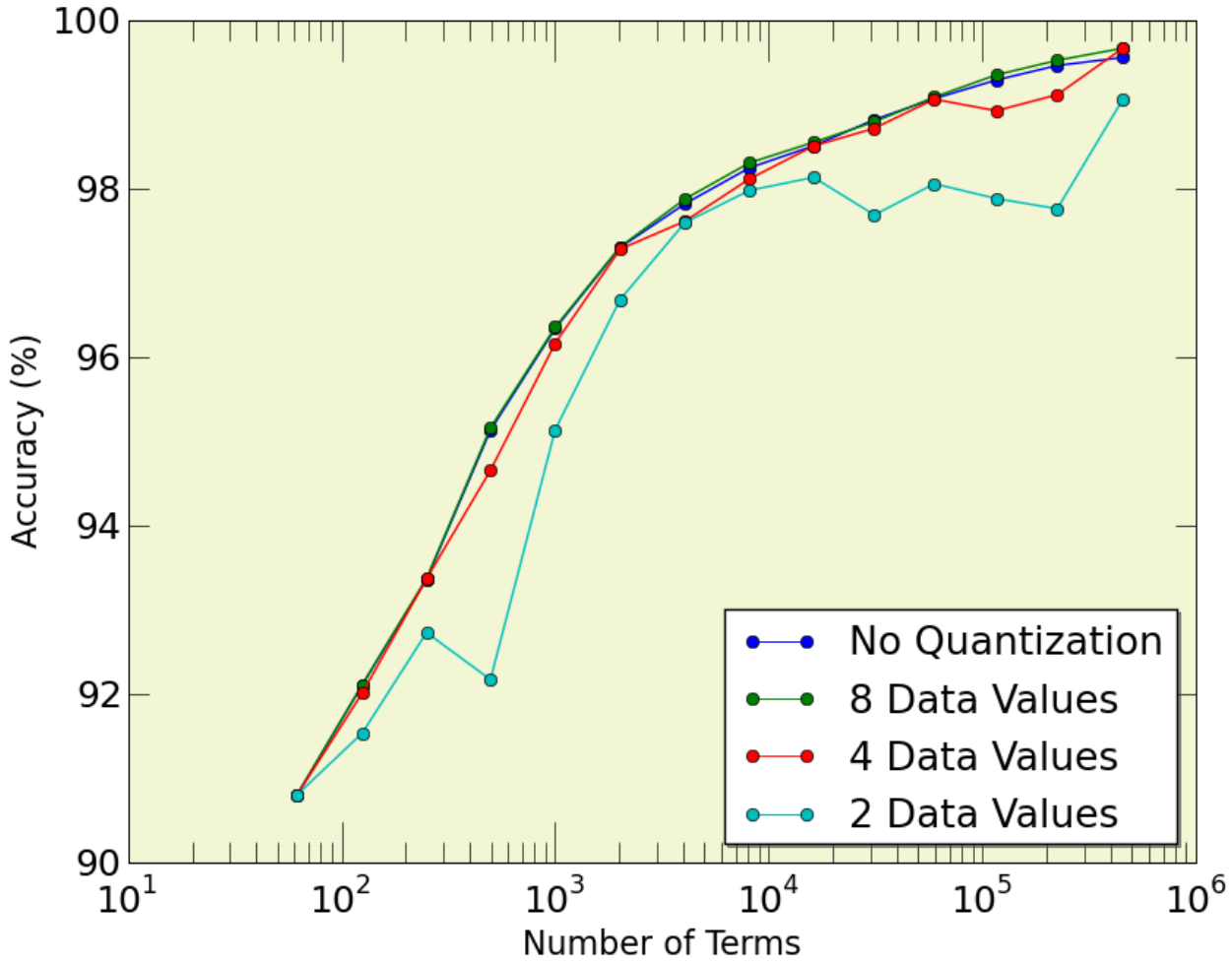
Quantization Impact on End Accuracy



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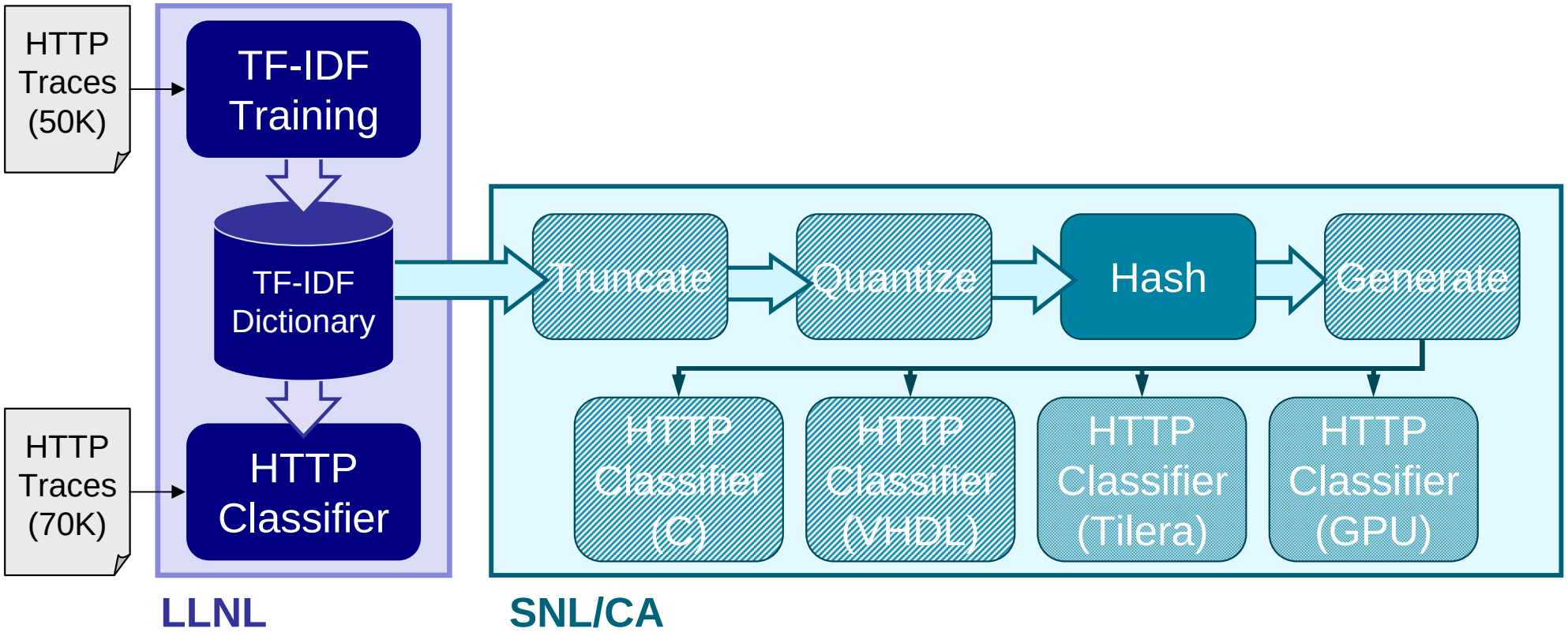

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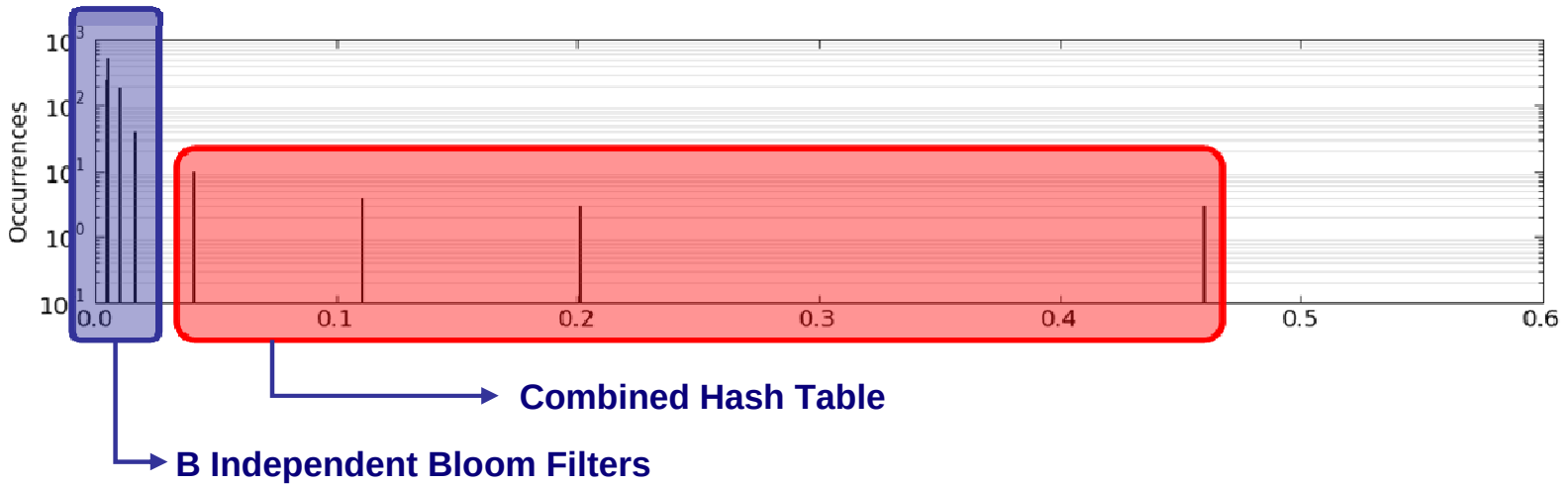
Hashing Tricks

- Small sets: combine into a single hash table
  - Brute-force packing sufficient for small tables
- Large sets: Array of Bloom filters
  - Bloom filters: space-efficient way to determine set membership
  - No false negatives, but can have false positives



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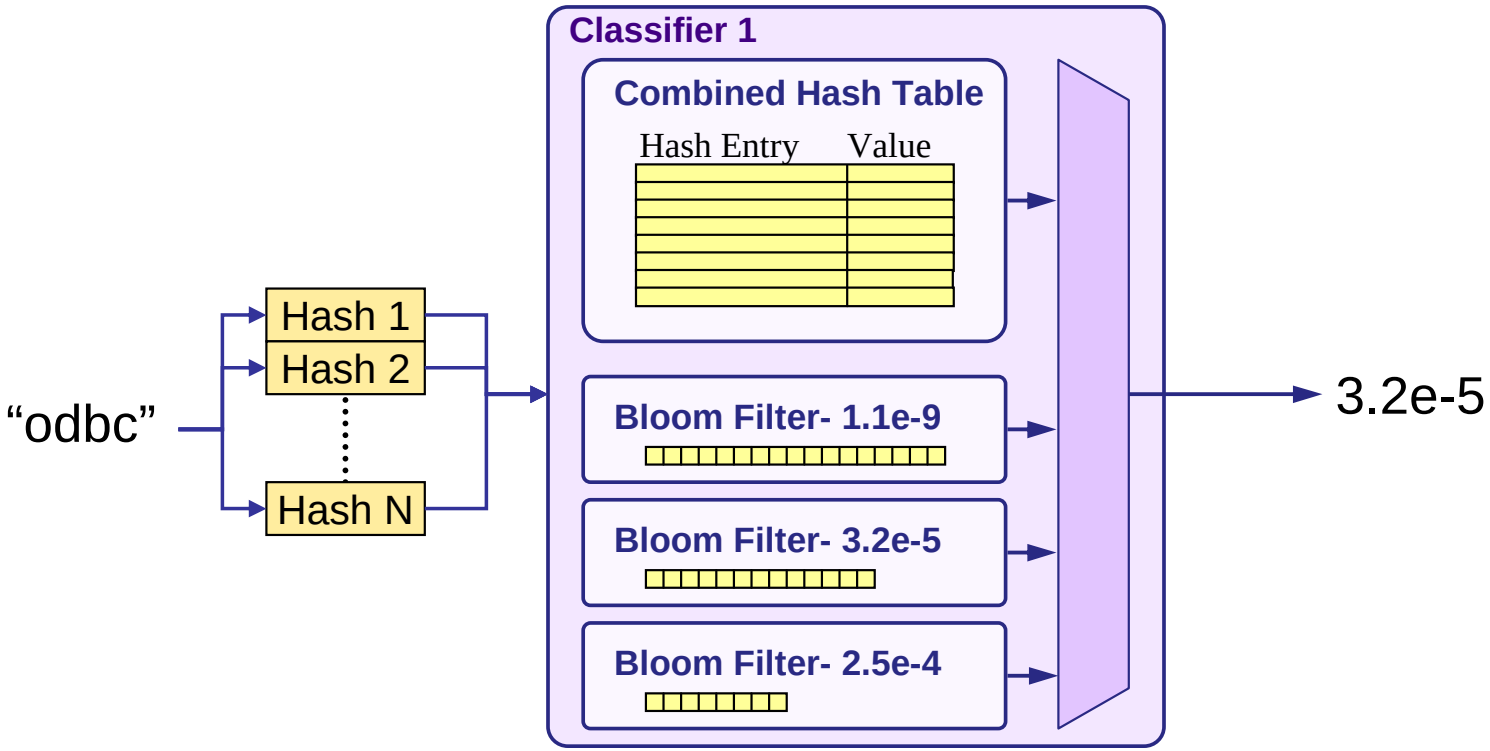
Hashing Replaces Dictionary



For 2KB Memory Block:

256 Hash table entries

~1K Bloom Filter members

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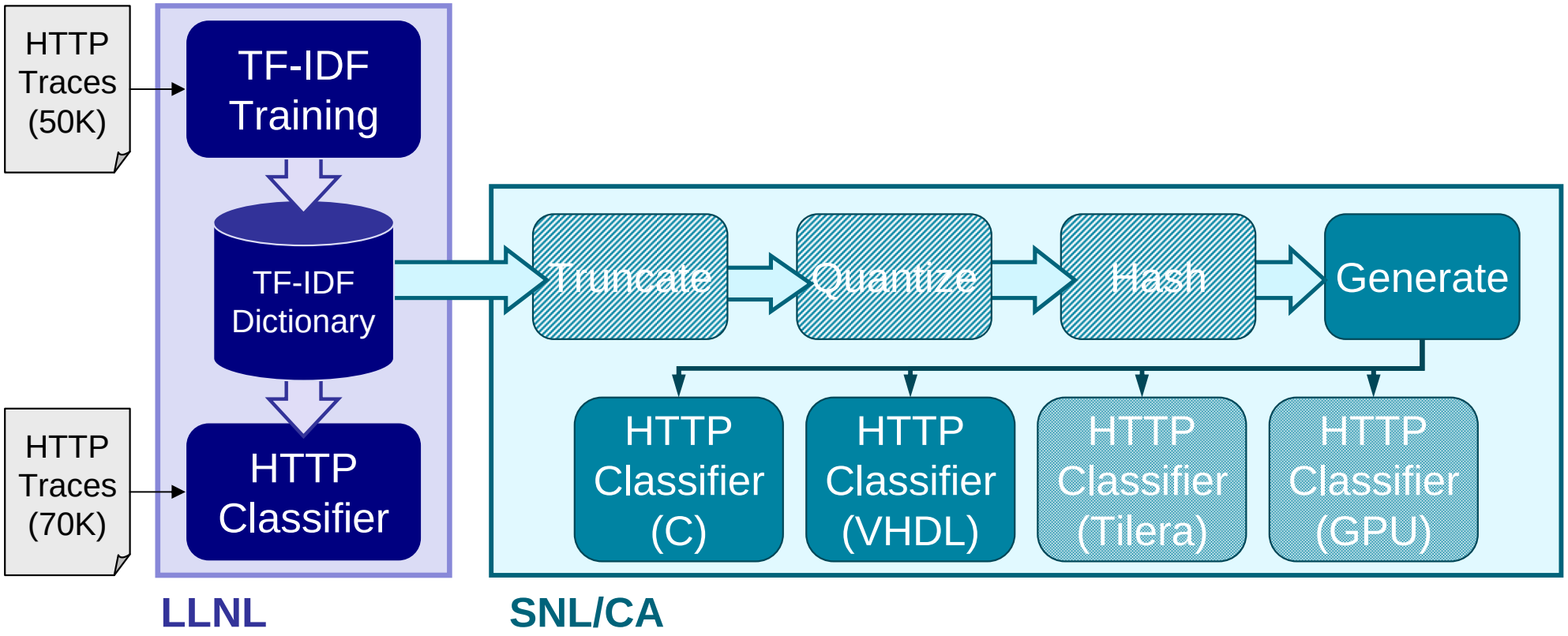

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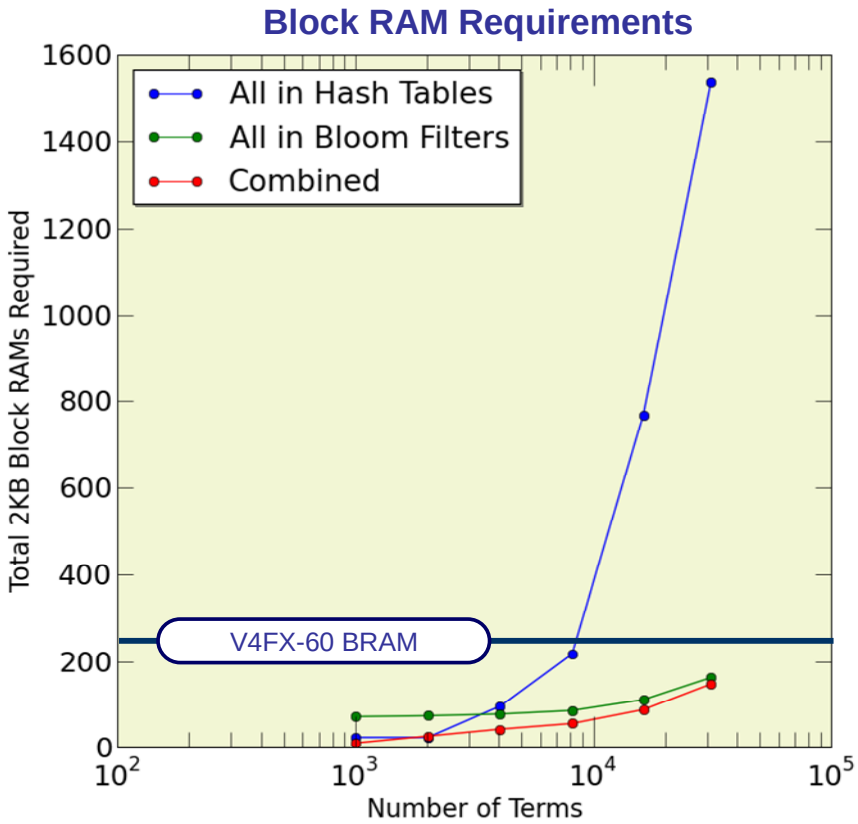
Generating Hardware

- Implemented flexible hardware design
  - Perl script converts data to parameters
- Piecewise testing
  - Full design in simulation software
  - Testing on new Virtex5 board
- Estimated speeds
  - 140MHz, >100MB/s
  - Bottleneck stream tokenizer



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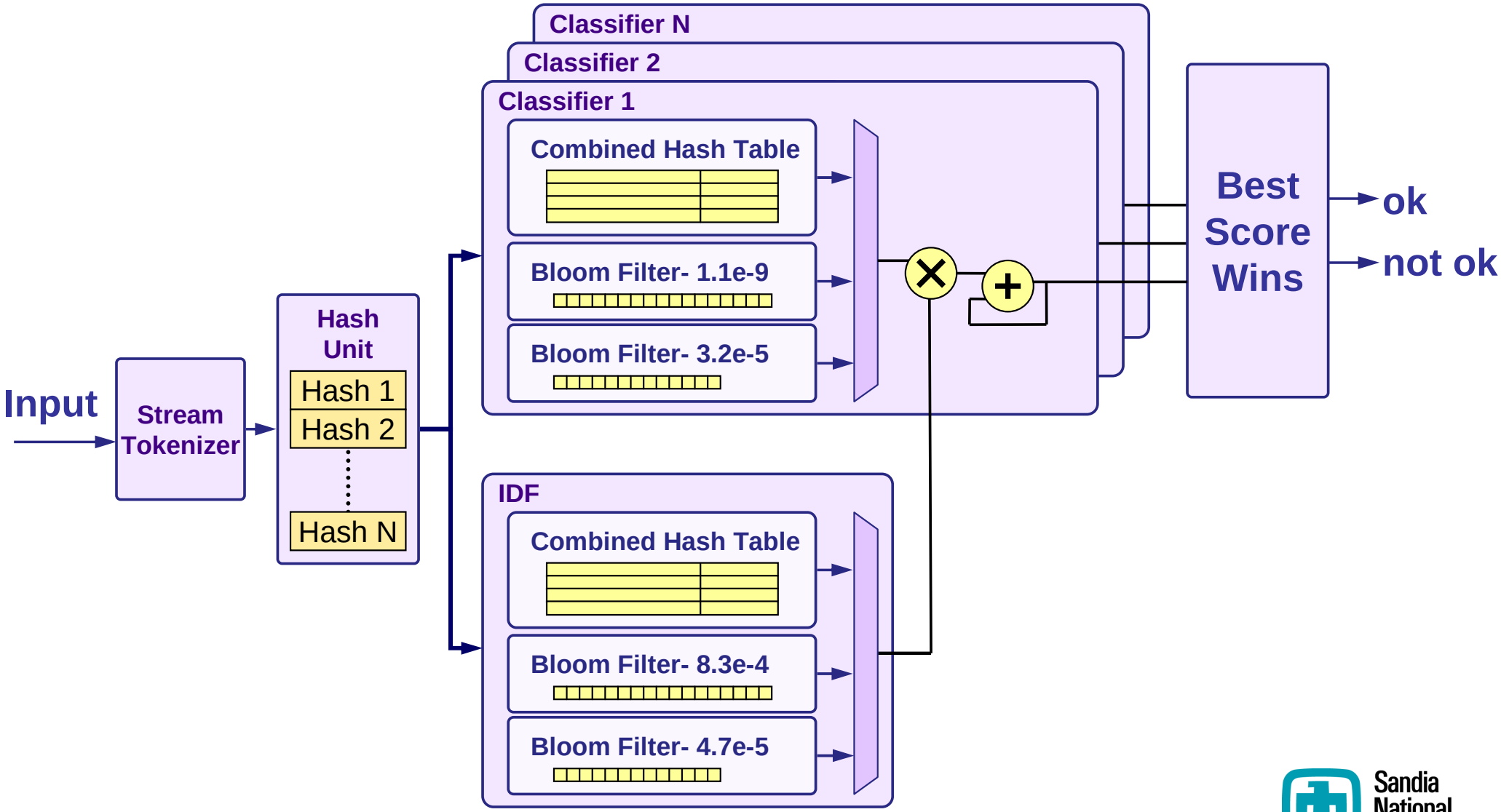
Hardware Data Flow



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Summary

- Adapted an HTTP classifier to embedded platforms
  - Confirmed and took advantage of wiggle room in dictionary
  - Hybrid approach to hashing works well
- Relevant in other classification applications
  - TF-IDF/Cosine Similarity is a standard approach
- Ongoing/Future Work
  - Finish out a demo system by the end of FY
  - Investigate port to Tilera and GPUs