LibFTE: A Toolkit for Constructing Practical, Format-Abiding Encryption Schemes

Daniel Luchaup, University of Wisconsin-Madison
Kevin P. Dyer, Portland State University
Somesh Jha, University of Wisconsin-Madison
Thomas Ristenpart, University of Wisconsin-Madison
Thomas Shrimpton, Portland State University

In-place encryption in database

Plaintext

Ciphertext

1234 5678 9876 5432 → **FPE** → 4417 1234 5678 9112

(Format-preserving encryption)
(Bellare et al. SAC'09)

Voltage security

Pci

Censorship circumvention

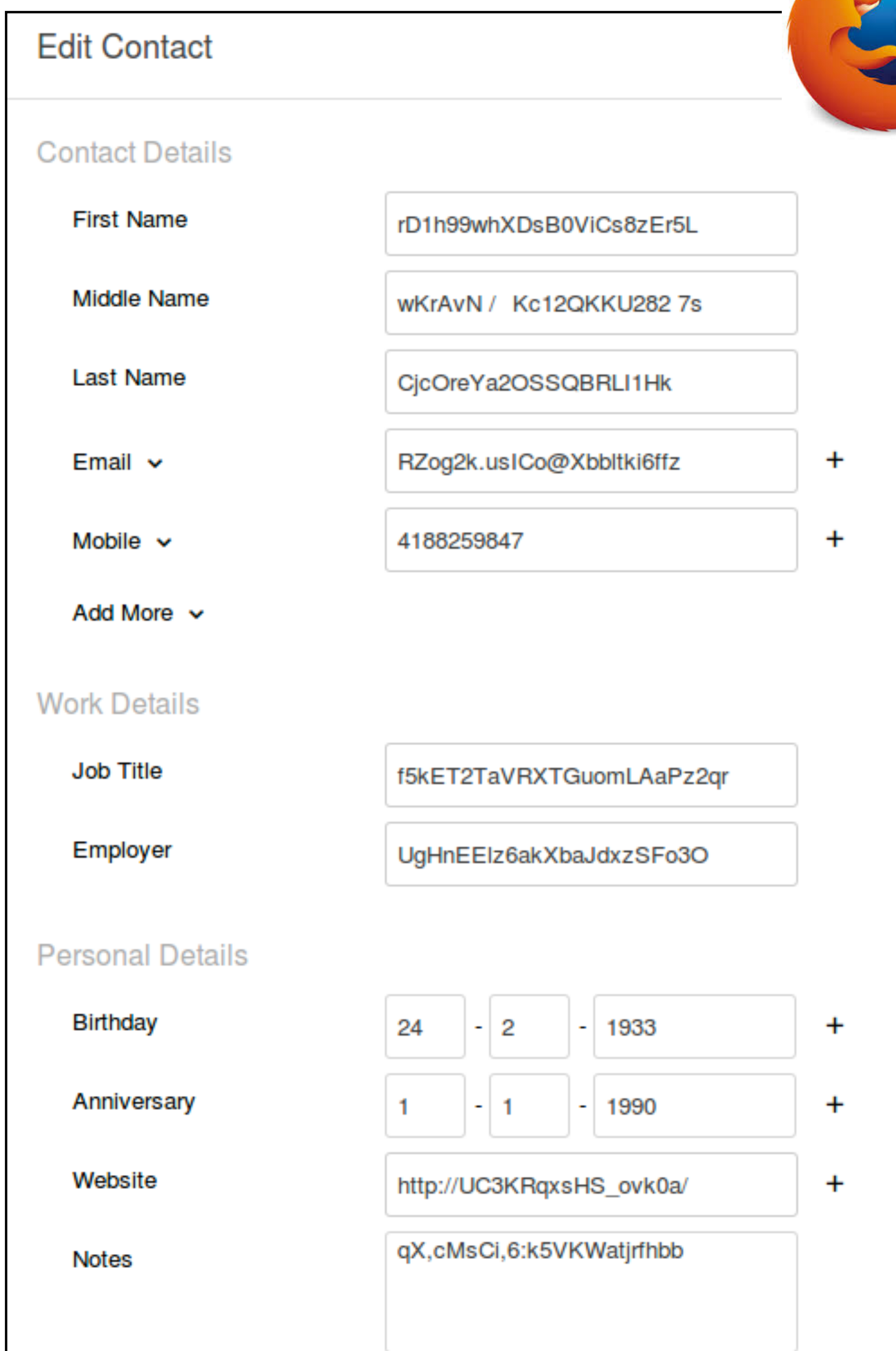
Plaintext → **FTE** → Ciphertext

or SMTP, SIP, RSTP, SSH,….

(Format-*transforming* encryption)

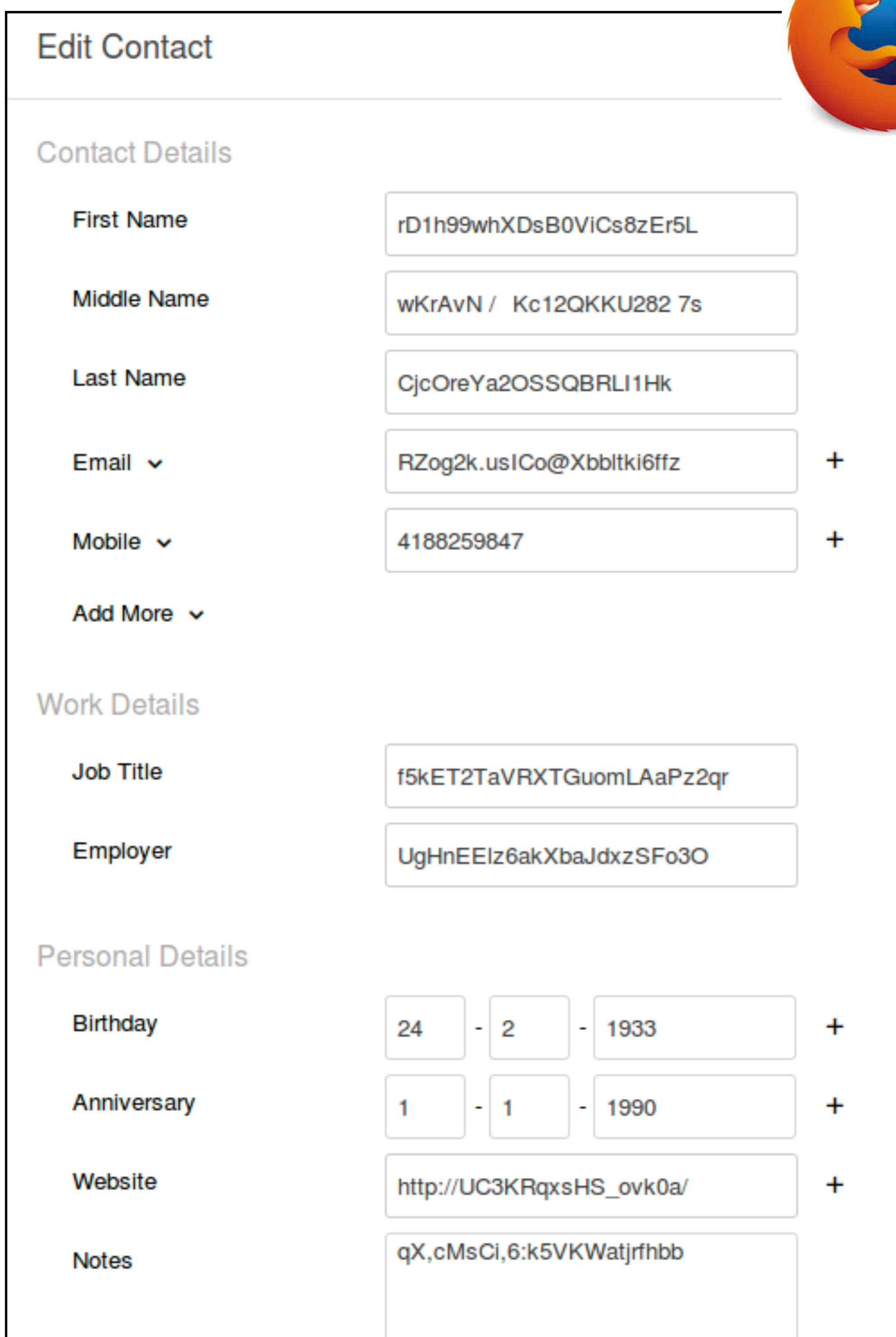
(Dyer et al. CCS’13)

What about other applications?



Expert knowledge required, substantial implementation and performance challenges.

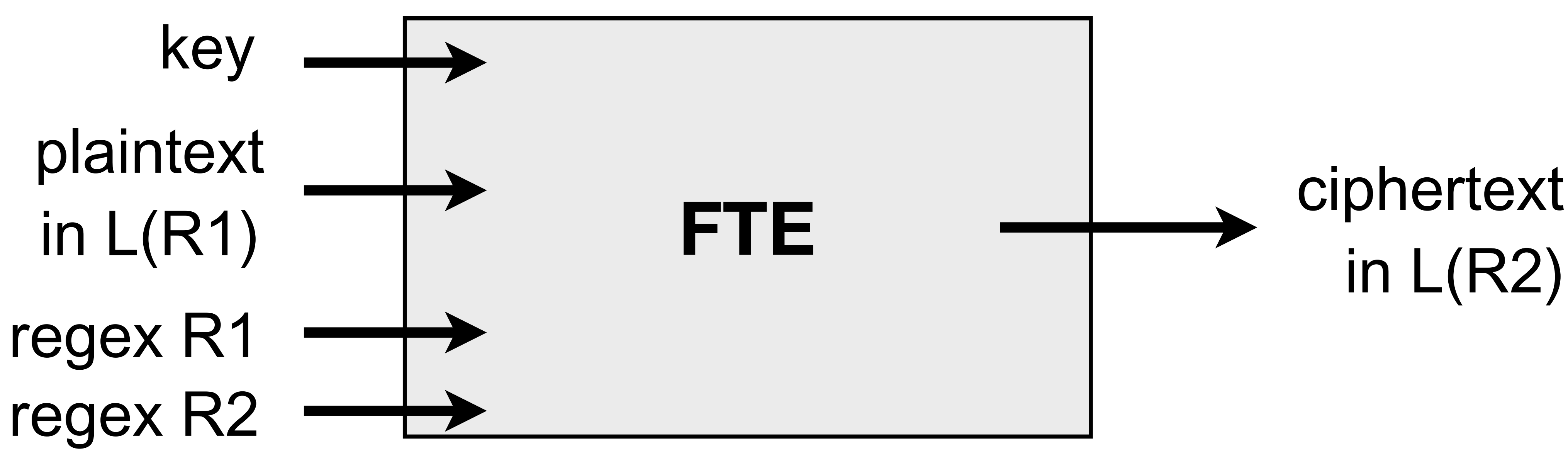
What about other applications?



Expert knowledge required, substantial implementation and performance challenges.

Our contribution: LibFTE

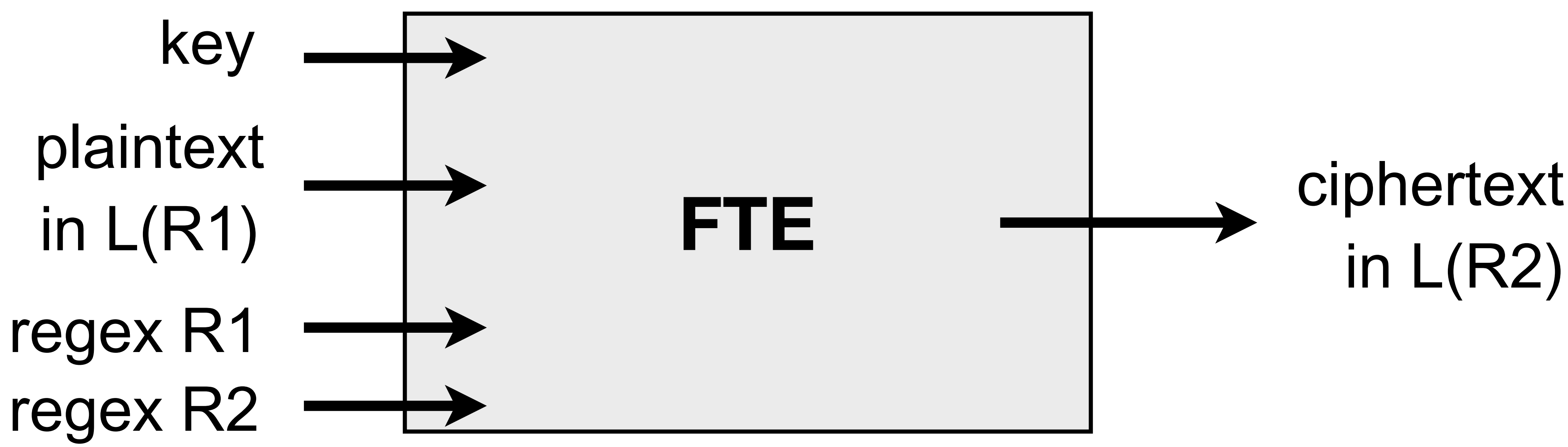
- **New algorithms to support this framework that solve open problem**
- **A general framework for building FTE (and FPE)**
- **A library (python/C++), and a toolkit to support development**



https://libfte.org/

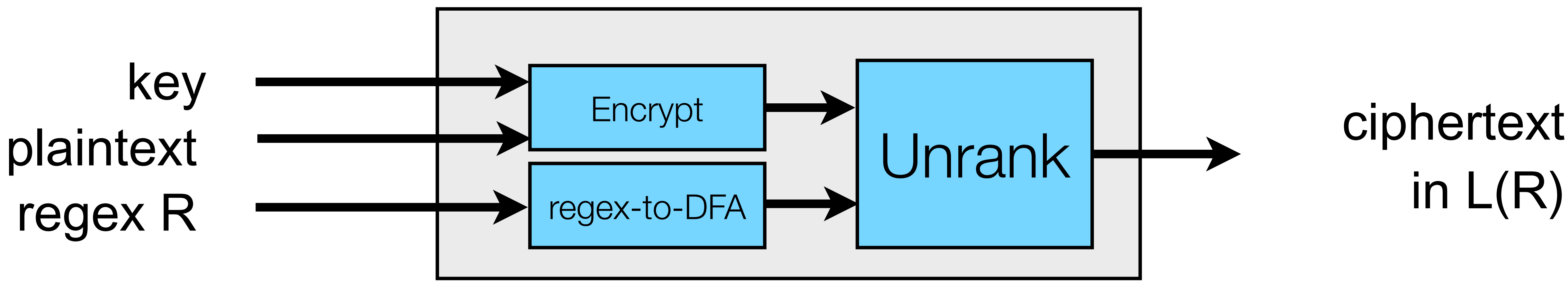
Our contribution: LibFTE

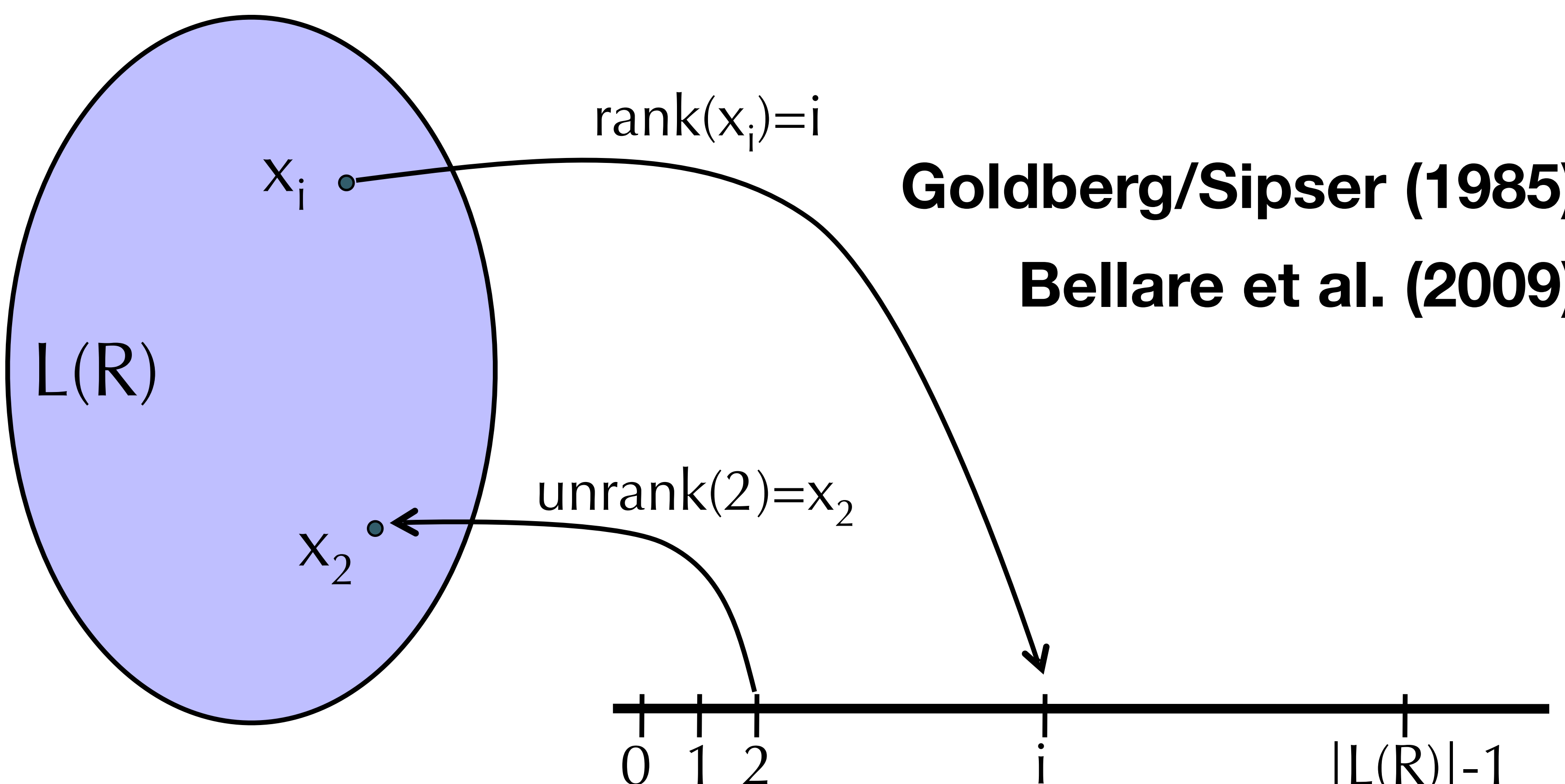
- **New algorithms to support this framework that solve open problem**
- **A general framework for building FTE (and FPE)**
- **A library (python/C++), and a toolkit to support development**



https://libfte.org/

The Previous FTE scheme (Dyer et al. 2013)

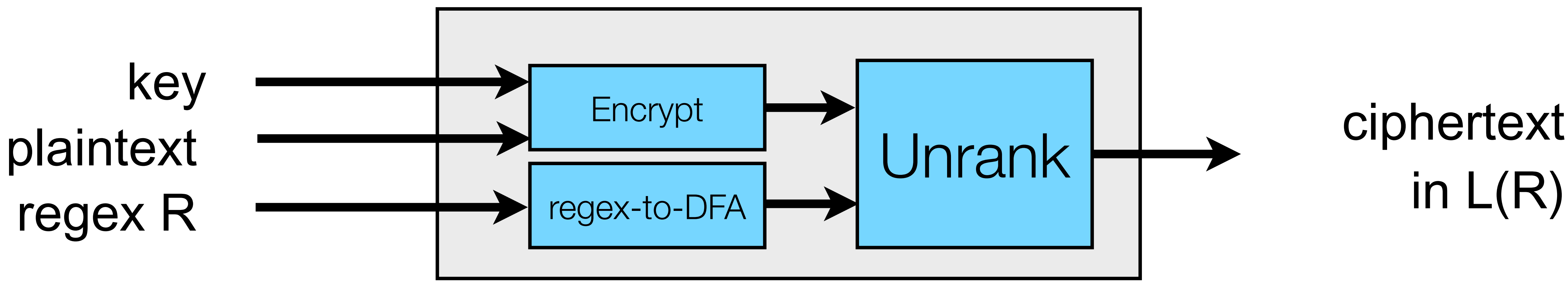


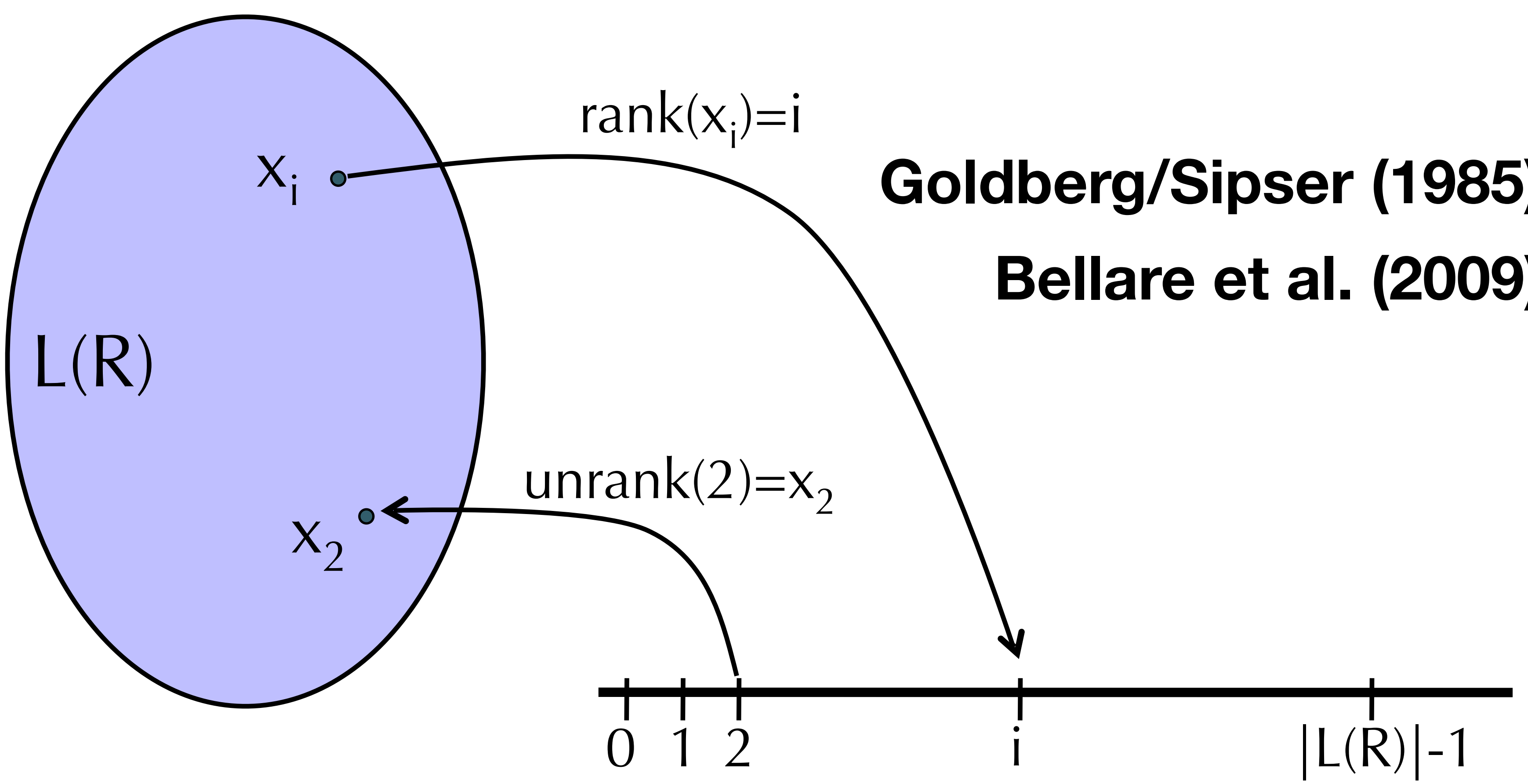


Goldberg/Sipser (1985)

Bellare et al. (2009)

The Previous FTE scheme (Dyer et al. 2013)

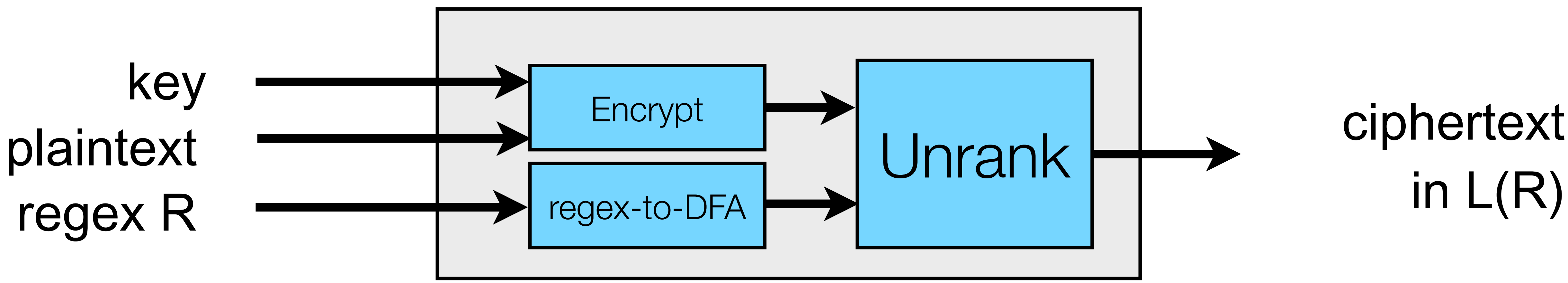


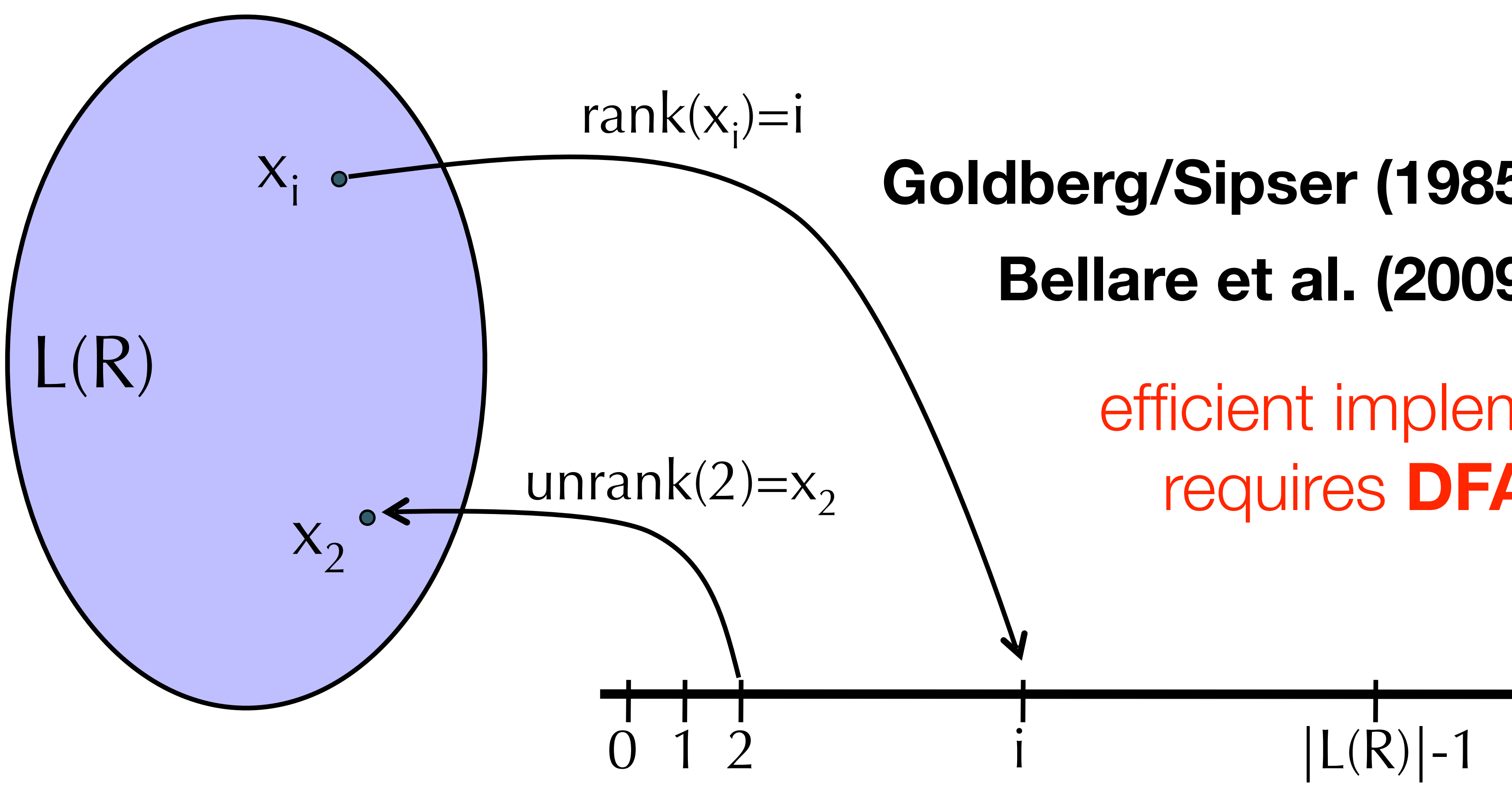


Goldberg/Sipser (1985)

Bellare et al. (2009)

The Previous FTE scheme (Dyer et al. 2013)



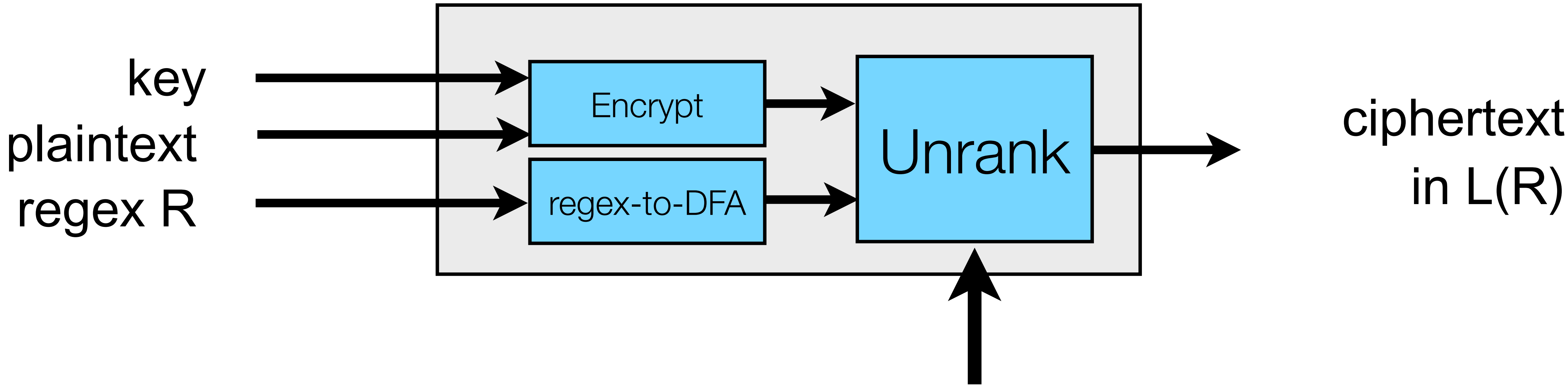


Goldberg/Sipser (1985)

Bellare et al. (2009)

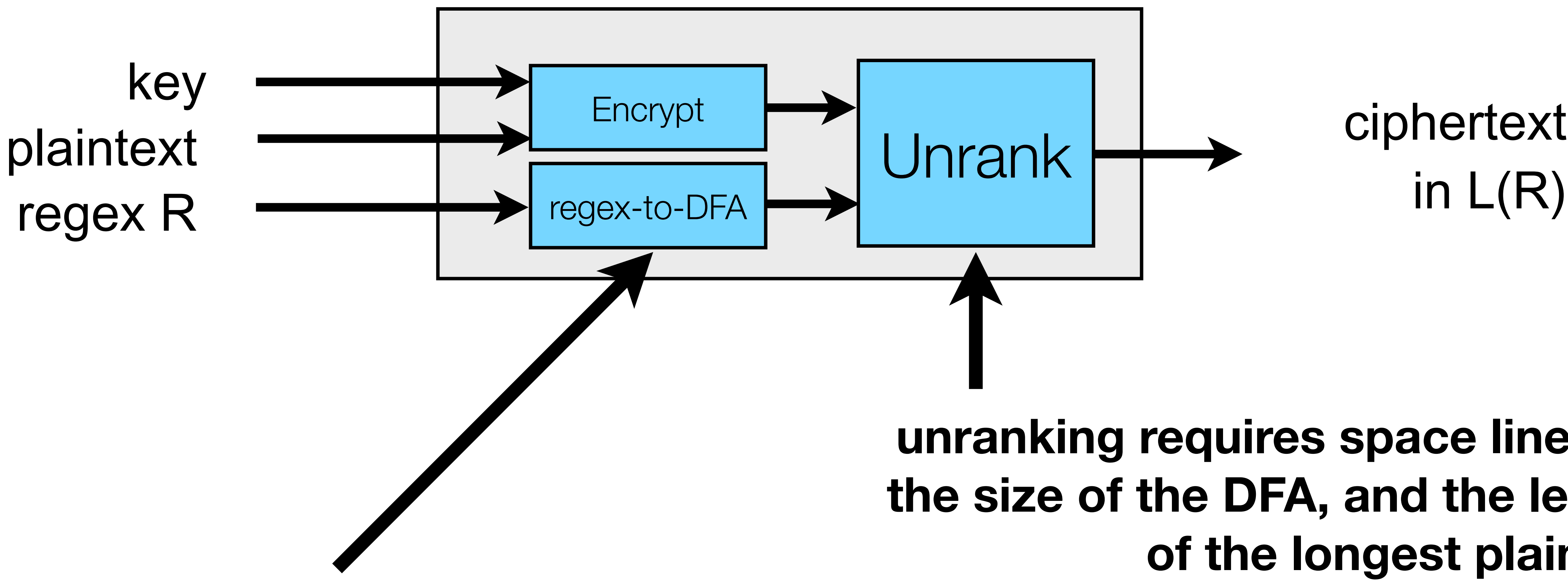
efficient implementation of (un)rank requires **DFA representation** of language

The Previous FTE scheme (Dyer et al. 2013)



unranking requires space linear in the size of the DFA, and the length of the longest plaintext

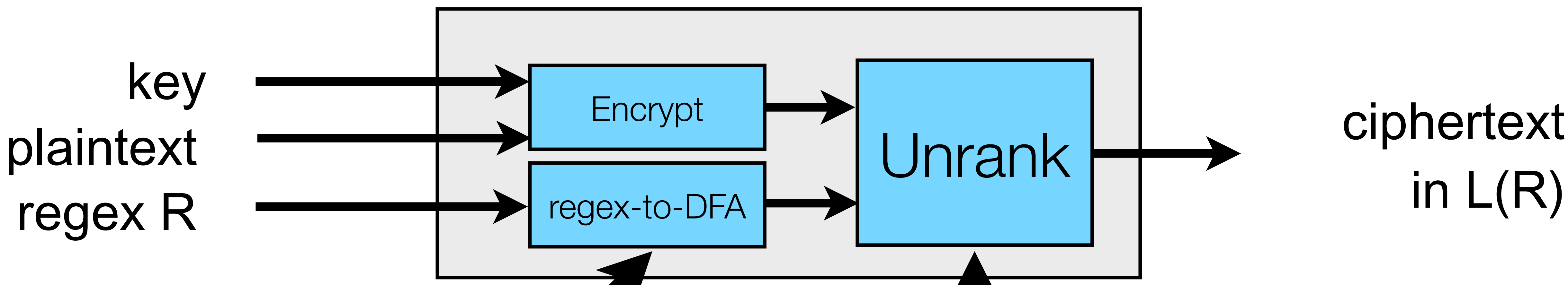
The Previous FTE scheme (Dyer et al. 2013)



unranking requires space linear in the size of the DFA, and the length of the longest plaintext

For some regular expressions, this works out just fine…

The Previous FTE scheme (Dyer et al. 2013)



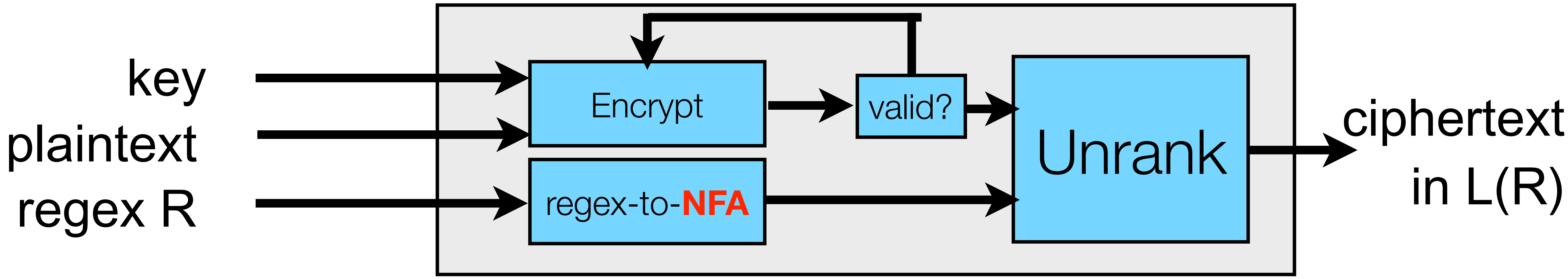
unranking requires space linear in the size of the DFA, and the length of the longest plaintext

…for others, you can have an *exponential* space blow-up

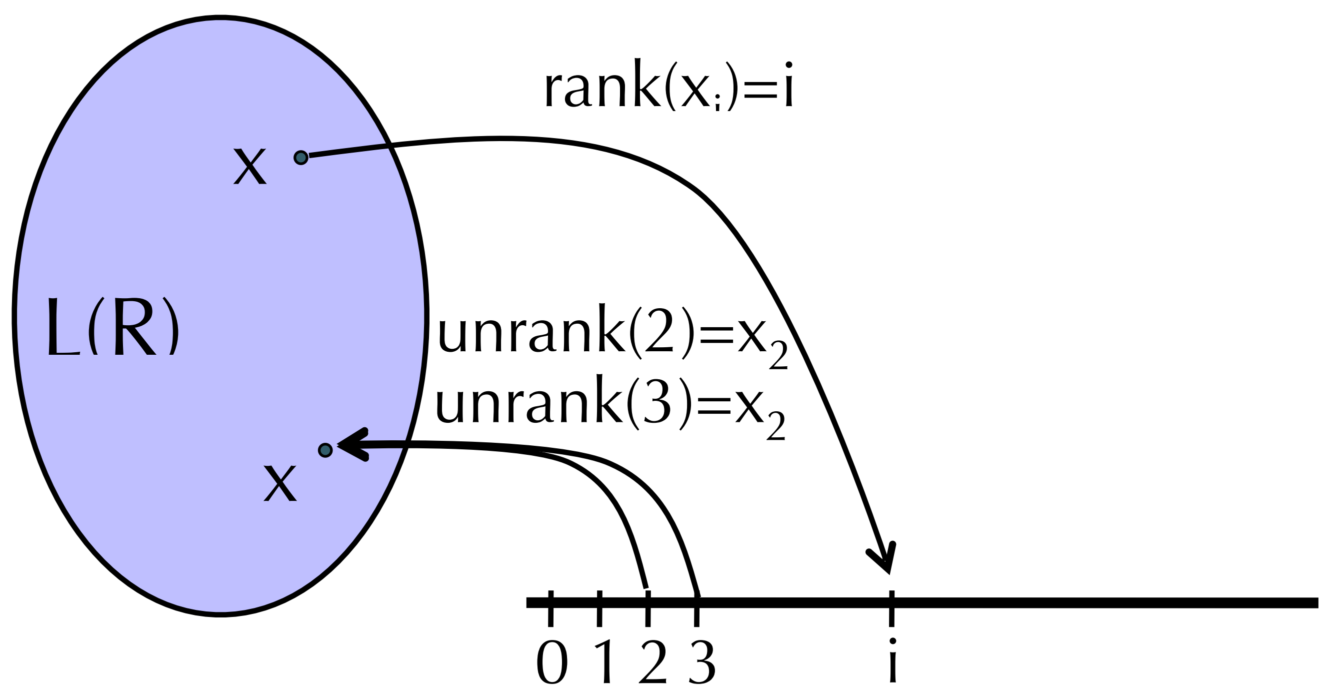
regex → NFA → DFA

A DFA with 13K states requires ~200MB of memory for (un)ranking. (Dyer et al., CCS'13)

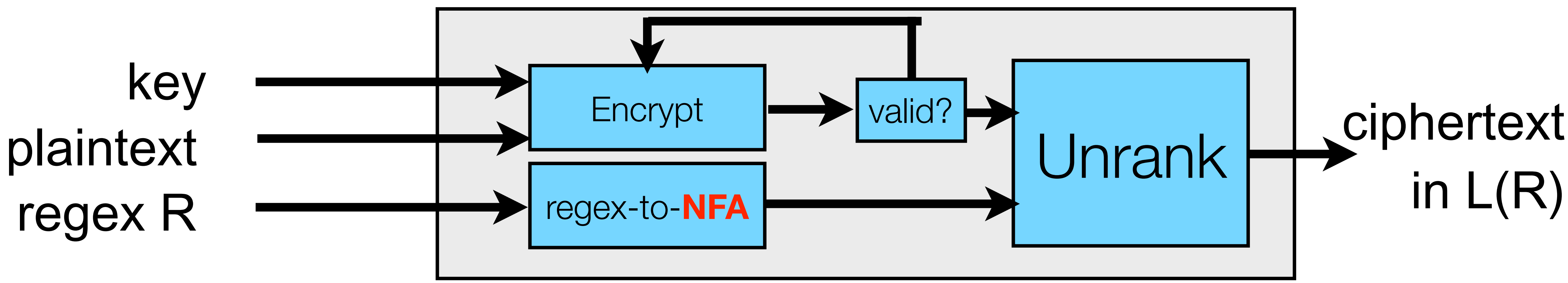
A new, NFA-based, FTE scheme



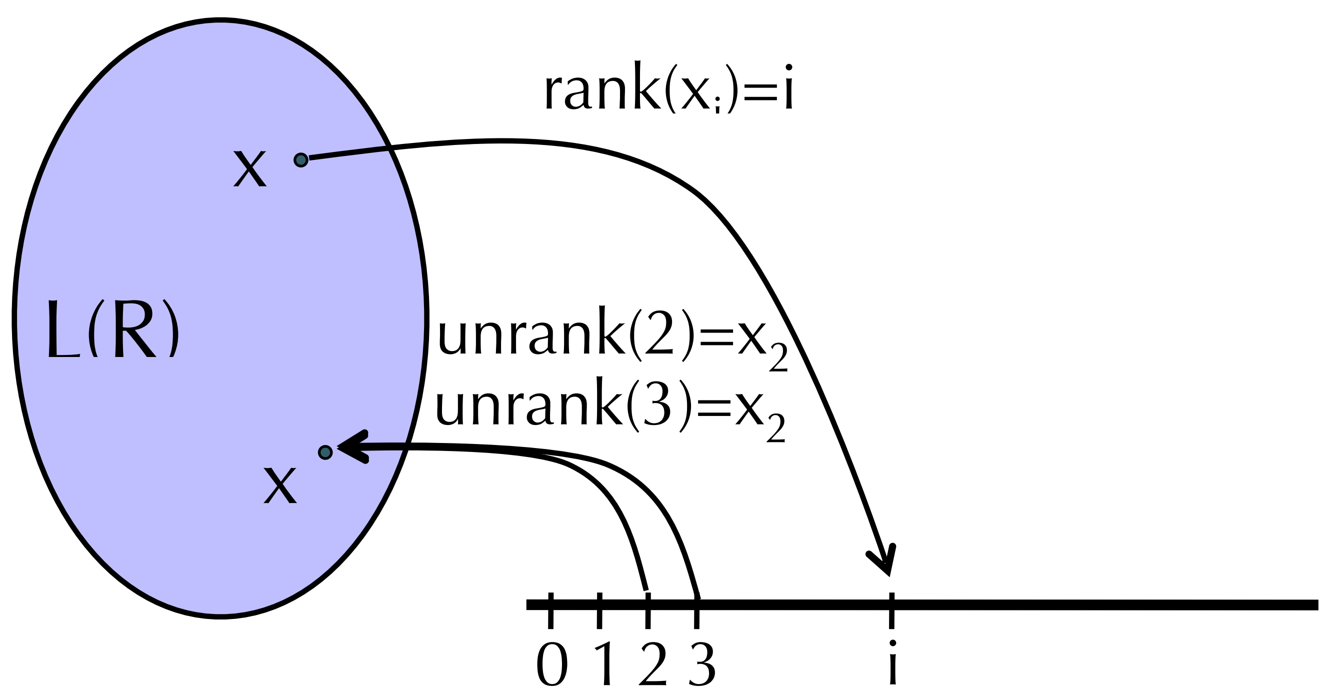
Based on new concept, *relaxed ranking:*



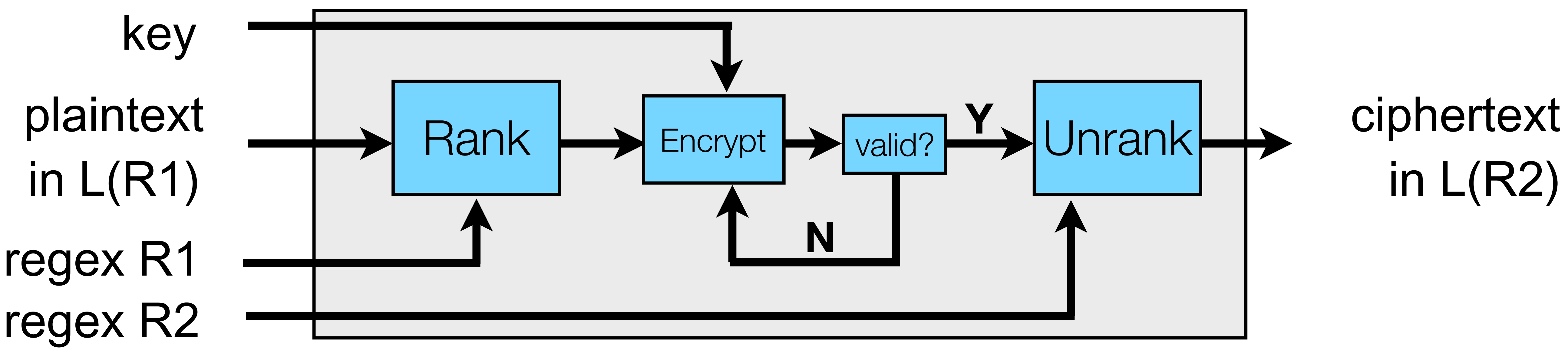
A new, NFA-based, FTE scheme



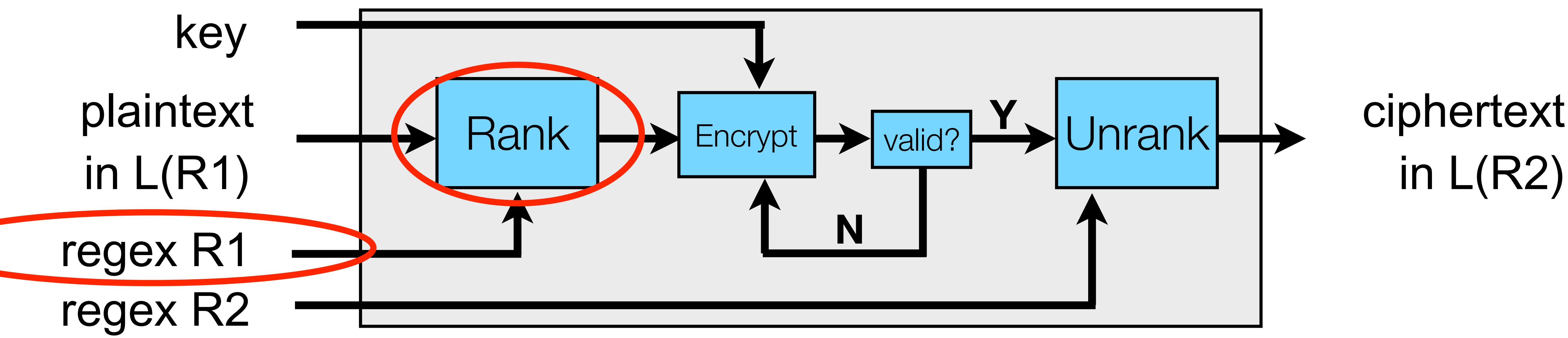
Based on new concept, *relaxed ranking:*



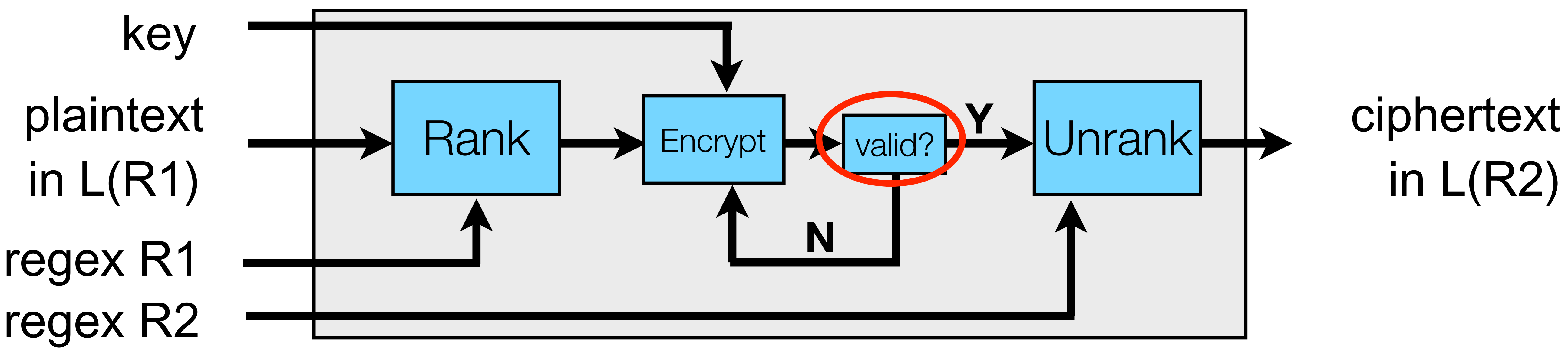
LibFTE framework is more general



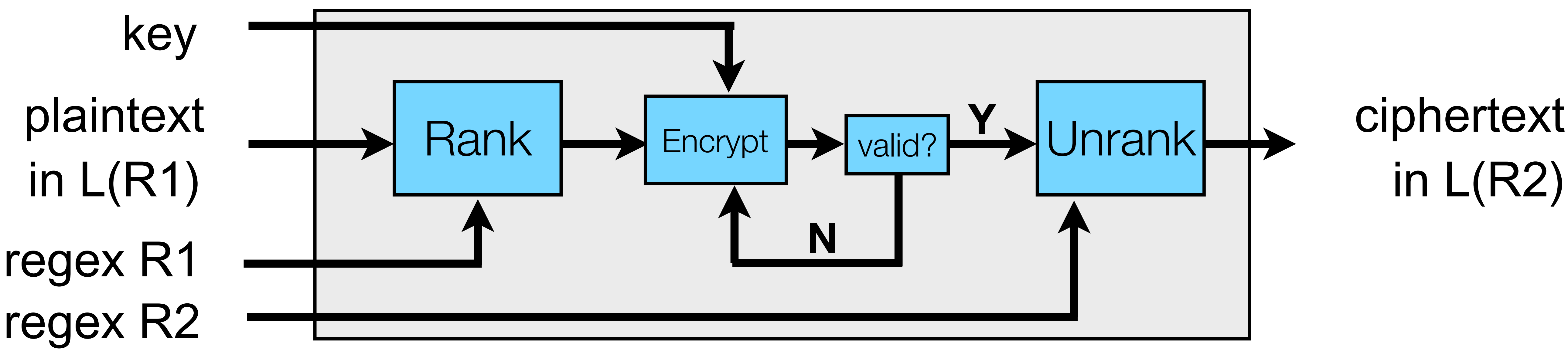
LibFTE framework is more general



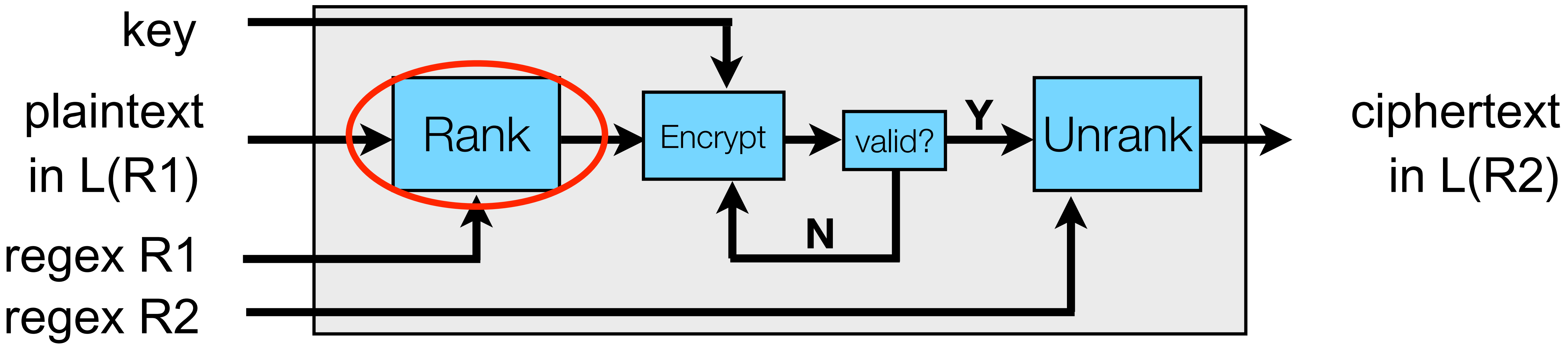
LibFTE framework is more general



LibFTE framework is more general

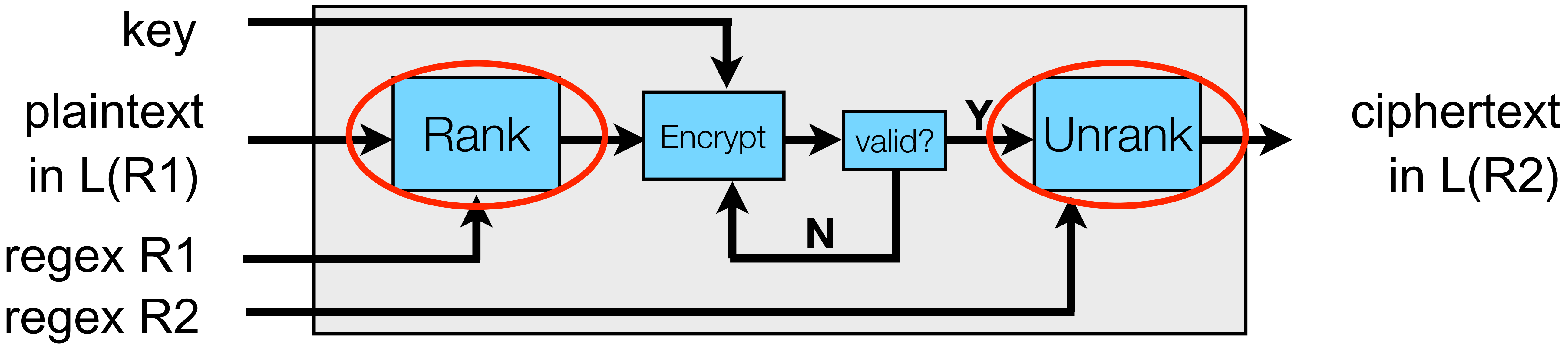


LibFTE framework is more general



NFA or DFA ranking for R1

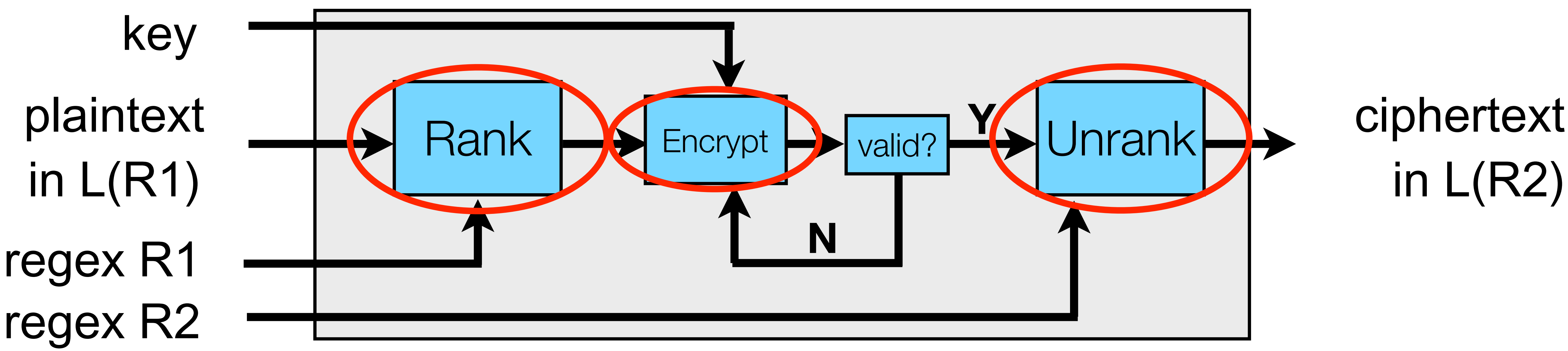
LibFTE framework is more general



NFA or DFA ranking for R1

NFA or DFA ranking for R2

LibFTE framework is more general

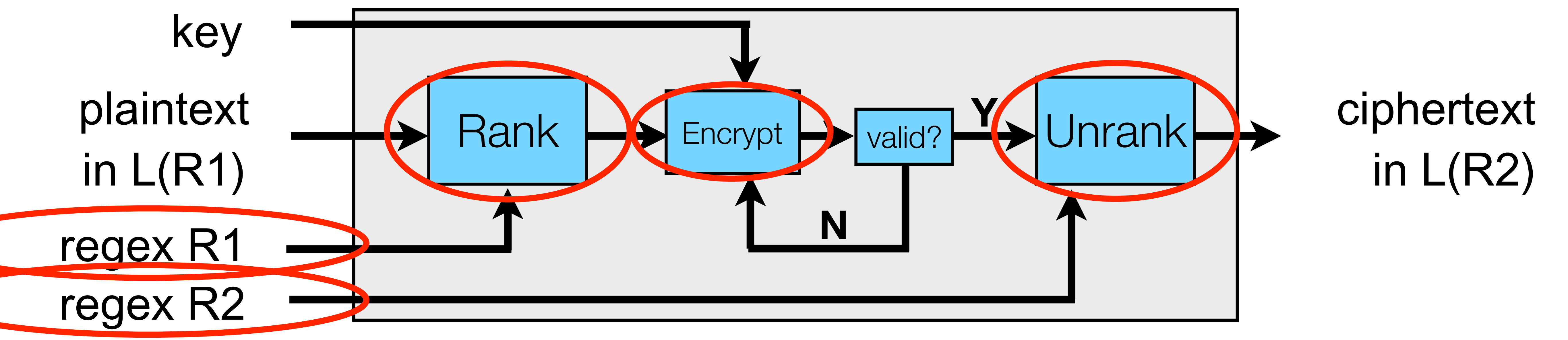


NFA or DFA ranking for R1

NFA or DFA ranking for R2

Deterministic or randomized encryption

LibFTE framework is more general



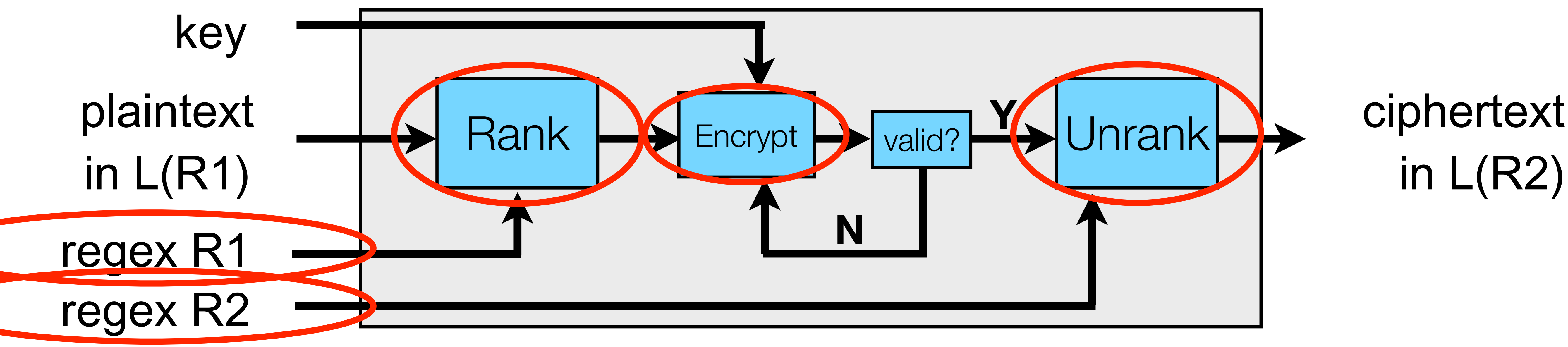
NFA or DFA ranking for R1

NFA or DFA ranking for R2

Deterministic or randomized encryption

Choice of regular expressions R1, R2

LibFTE framework is more general



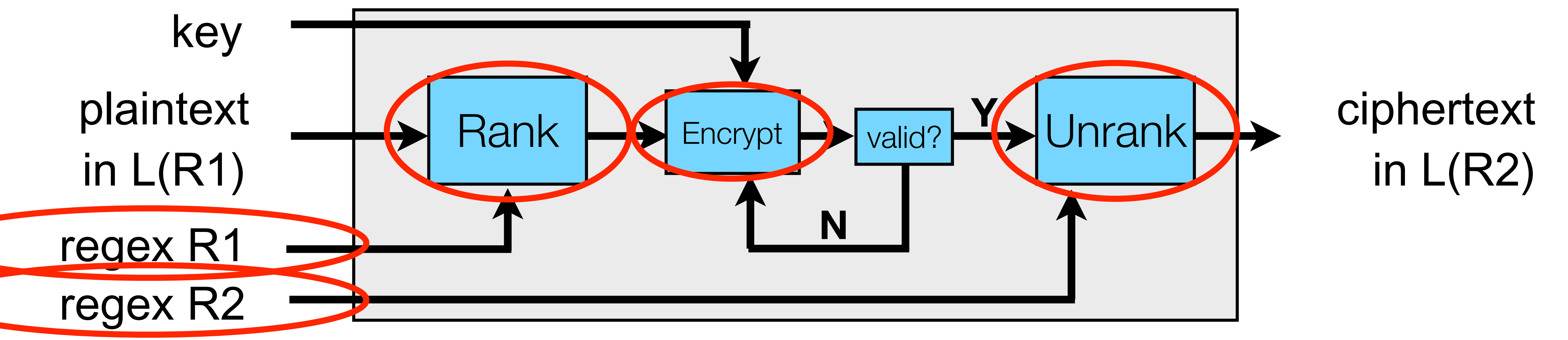
NFA or DFA ranking for R1

NFA or DFA ranking for R2

Deterministic or randomized encryption

Choice of regular expressions R1, R2

LibFTE framework is more general



NFA or DFA ranking for R1

NFA or DFA ranking for R2

Deterministic or randomized encryption

Choice of regular expressions R1, R2

LibFTE Configuration Assistant

input: input format, output format, and optional restrictions (e.g., encryption must be randomized/deterministic)

output: an error OR a list of schemes that satisfy the user-specified constraints, with statistics (no. cycle walks, etc.)

```
$ ./configuration-assistant \
>  --input-format "(a|b)*a(a|b){16}" 0 64 \
>  --output-format "[0-9a-f]{16}" 0 16

==== Identifying valid schemes ====
No valid schemes.
ERROR: Input language size greater than
output language size.
$
```

error

OR

```
$ ./configuration-assistant \
>  --input-format "(a|b)*a(a|b){16}" 0 32 \
>  --output-format "[0-9a-f]{16}" 0 16

==== Identifying valid schemes ====
WARNING: Memory threshold exceeded when
         building DFA for input format
VALID SCHEMES: T-ND, T-NN,
               T-ND-$, T-NN-$

==== Evaluating valid schemes  ====
SCHEME ENCRYPT DECRYPT ... MEMORY
T-ND   0.32ms  0.31ms  ... 77KB
T-NN   0.39ms  0.38ms  ... 79KB
…
$
```

success

LibFTE Configuration Assistant

input: input format, output format, and optional restrictions (e.g., encryption must be randomized/deterministic)

output: an error OR a list of schemes that satisfy the user-specified constraints, with statistics (no. cycle walks, etc.)

```
$ ./configuration-assistant \
>  --input-format "(a|b)*a(a|b){16}" 0 64 \
>  --output-format "[0-9a-f]{16}" 0 16

==== Identifying valid schemes ====
No valid schemes.
ERROR: Input language size greater than
output language size.
$
```

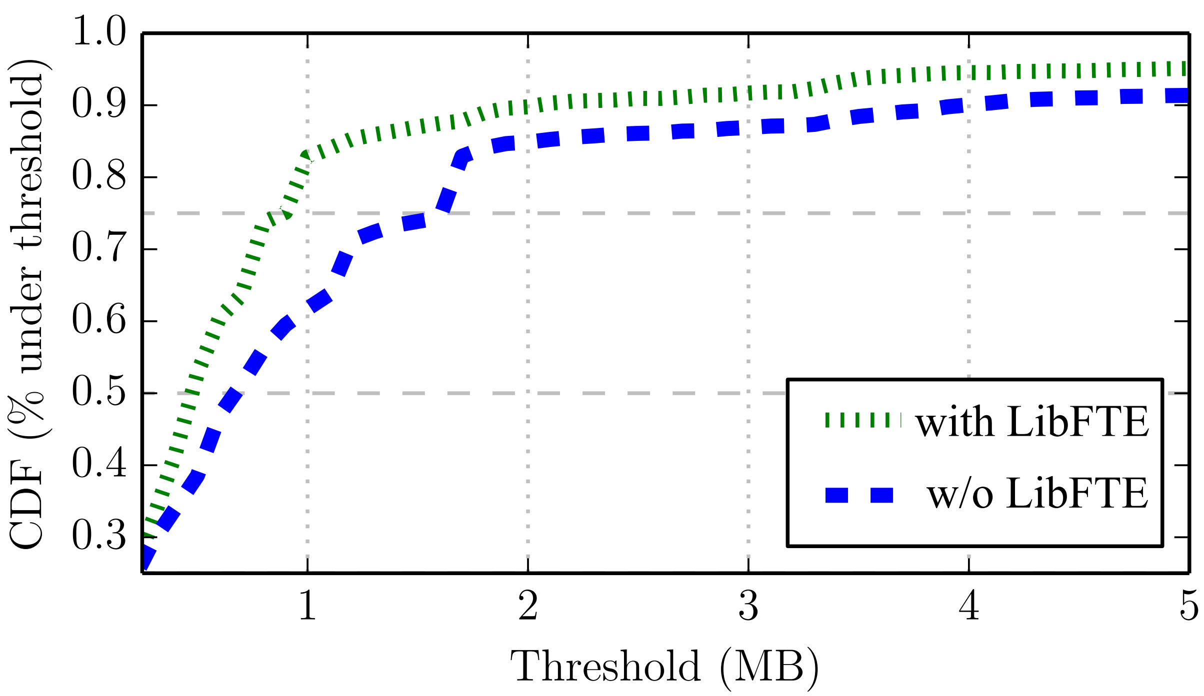
OR

```
$ ./configuration-assistant \
>  --input-format "(a|b)*a(a|b){16}" 0 32 \
>  --output-format "[0-9a-f]{16}" 0 16

==== Identifying valid schemes ====
WARNING: Memory threshold exceeded when
         building DFA for input format
VALID SCHEMES: T-ND, T-NN,
               T-ND-$, T-NN-$

==== Evaluating valid schemes  ====
SCHEME ENCRYPT DECRYPT ... MEMORY
T-ND   0.32ms  0.31ms  ... 77KB
T-NN   0.39ms  0.38ms  ... 79KB
…
$
```

error **success**

Case Studies

LibFTE: Snort IDS Regexs

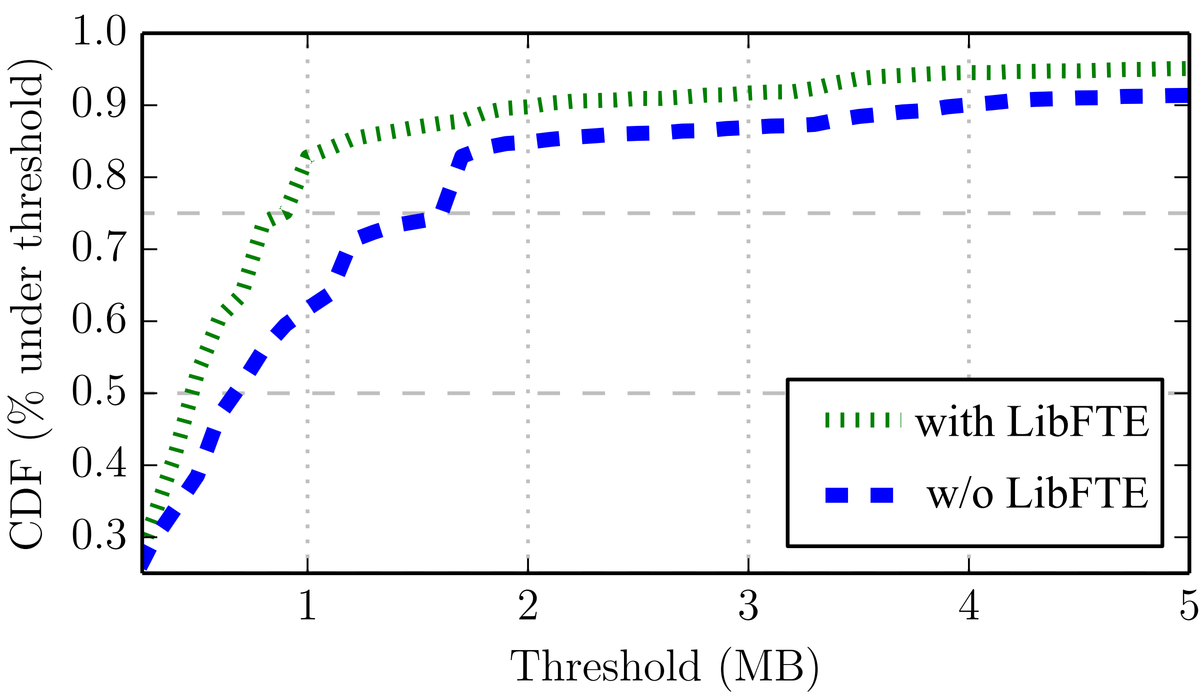


- **Used a set of ~3.5K regexs from the Snort corpus.**
  A good stress test.

- **Reduced avg. memory by 30%.**
  In some cases by orders of magnitude.

- **Handled extreme cases (~3%) where DFA ranking fails.**
  All 3.5K regexs could be used with <150MB of memory using NFA ranking.

LibFTE: Snort IDS Regexs



- **Used a set of ~3.5K regexs from the Snort corpus.**
  A good stress test.

- **Reduced avg. memory by 30%.**
  In some cases by orders of magnitude.

- **Handled extreme cases (~3%) where DFA ranking fails.**
  All 3.5K regexs could be used with <150MB of memory using NFA ranking.

LibFTE: Database encryption+compression

- **Compare against PostgreSQL encryption library.**
  Because there does not exist any public implementation of FPE/FFX.

- **Created a table with credit card numbers.**
  Then tested under various configurations.

	Database Configuration				
	PSQL	**+AES**	**+AE**	**+FPE**	**+FTE**
Table Size	50MB	65MB	112MB	50MB	42MB
Query Avg.	74ms	92ms	112ms	125ms	110ms

Query Avg. = time to retrieve 1000 CC nums

LibFTE: Database encryption+compression

- **Compare against PostgreSQL encryption library.**
  Because there does not exist any public implementation of FPE/FFX.

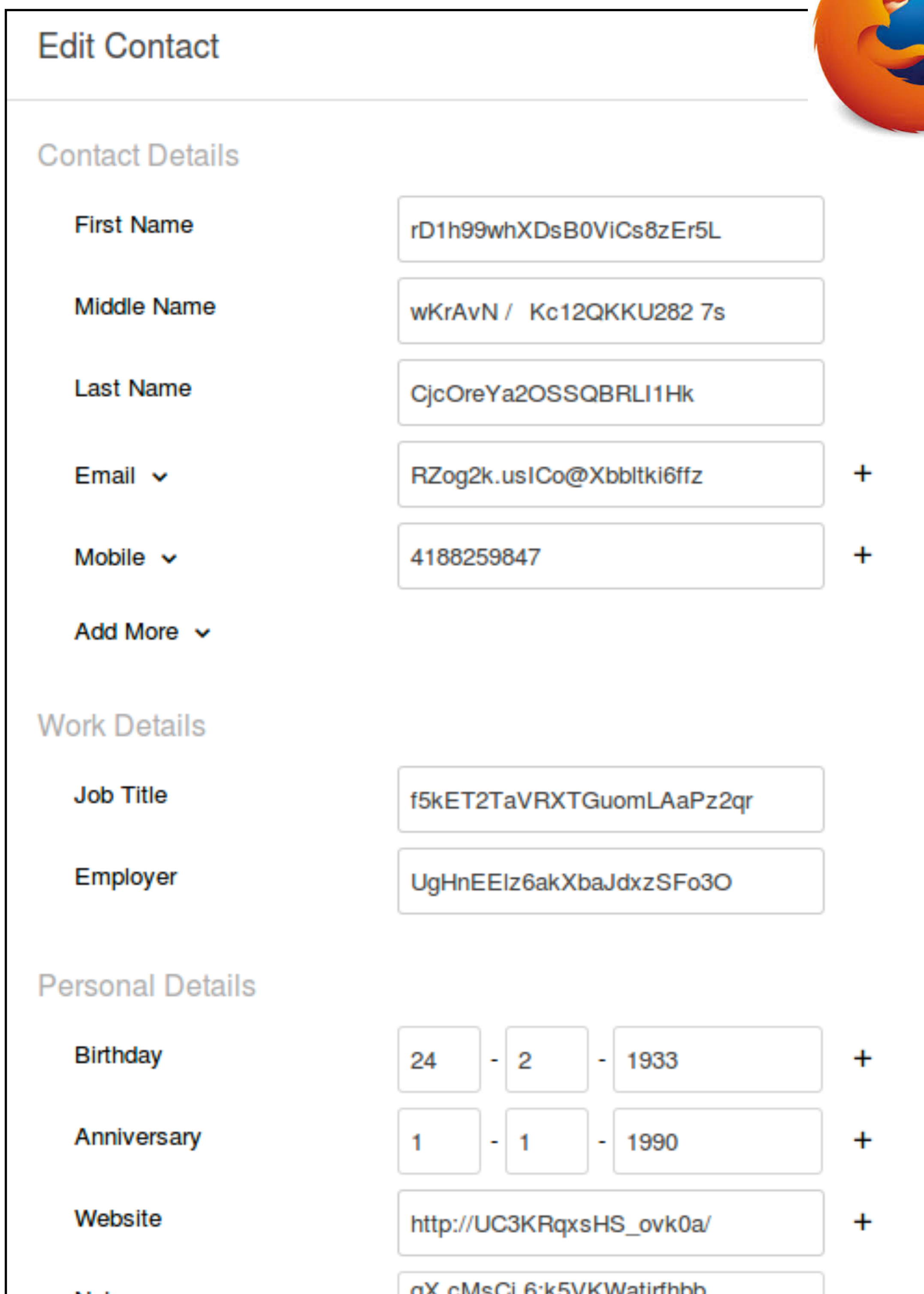
- **Created a table with credit card numbers.**
  Then tested under various configurations.

Compared to AES, LibFTE saves ~35% on disk.

	Database Configuration				
	PSQL	**+AES**	**+AE**	**+FPE**	**+FTE**
Table Size	50MB	65MB	112MB	50MB	42MB
Query Avg.	74ms	92ms	112ms	125ms	110ms

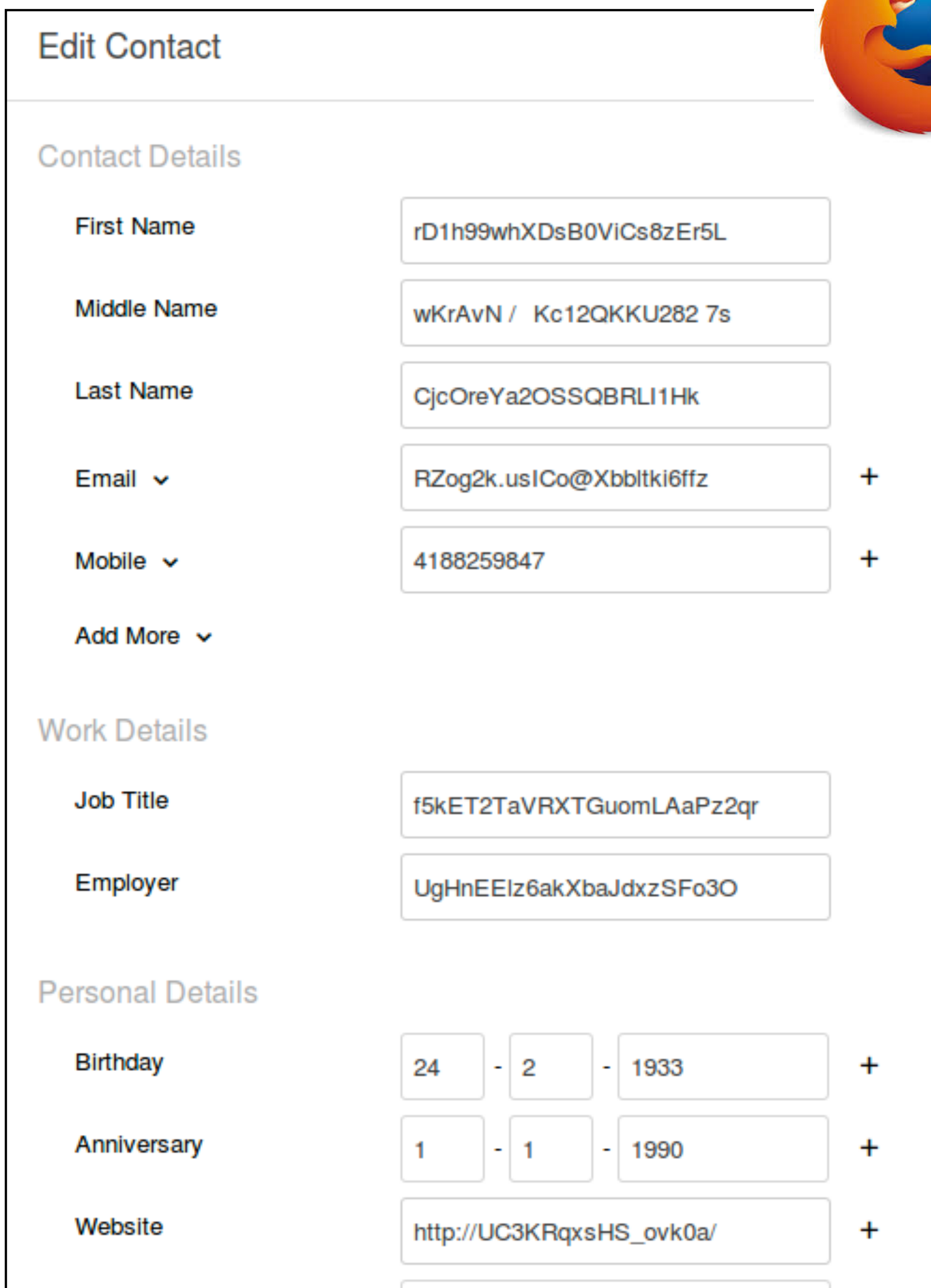
Query Avg. = time to retrieve 1000 CC nums

LibFTE: Firefox extension



- **A pure-Javascript LibFTE interface.**
- **We created a mapping between fields and FPE/FTE schemes.**
  Simple, using CSS id/class attrs.
- **Using libfte: only 20 lines of code**

LibFTE: Firefox extension



- **A pure-Javascript LibFTE interface.**
- **We created a mapping between fields and FPE/FTE schemes.**
  Simple, using CSS id/class attrs.
- **Using libfte: only 20 lines of code**

Conclusion: LibFTE

- **A general framework for building FTE (and FPE) schemes.**
  No one-off, per-deployment solutions.

- **New algorithmic advances.**
  Abstracts away clunky design choices.

- **Surfaced new use cases.**
  Compression+encryption, in-browser encryption.

- **High-performance, publicly available.**
  APIs for C++ and Python.

https://libfte.org/