Finding Real Bugs in Big Programs with Incorrectness Logic

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KAIST

Background

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  - Analyze parts of the program (functions) first, then combines them
  - Enables diff-time analysis for fast results
- Over 100,000 bug reports were fixed

Limitation: Discrepancy

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Use of Static Analysis in practice

- “Bug means a bug”
- Developers does not want false alarms

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Pulse-X

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- Static Analyzer based on Incorrectness Separation Logic (ISL).

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- Compositional and Under-approximated analysis
- 1.5 time higher fix rate over Infer
- Found 15 new bugs in OpenSSL

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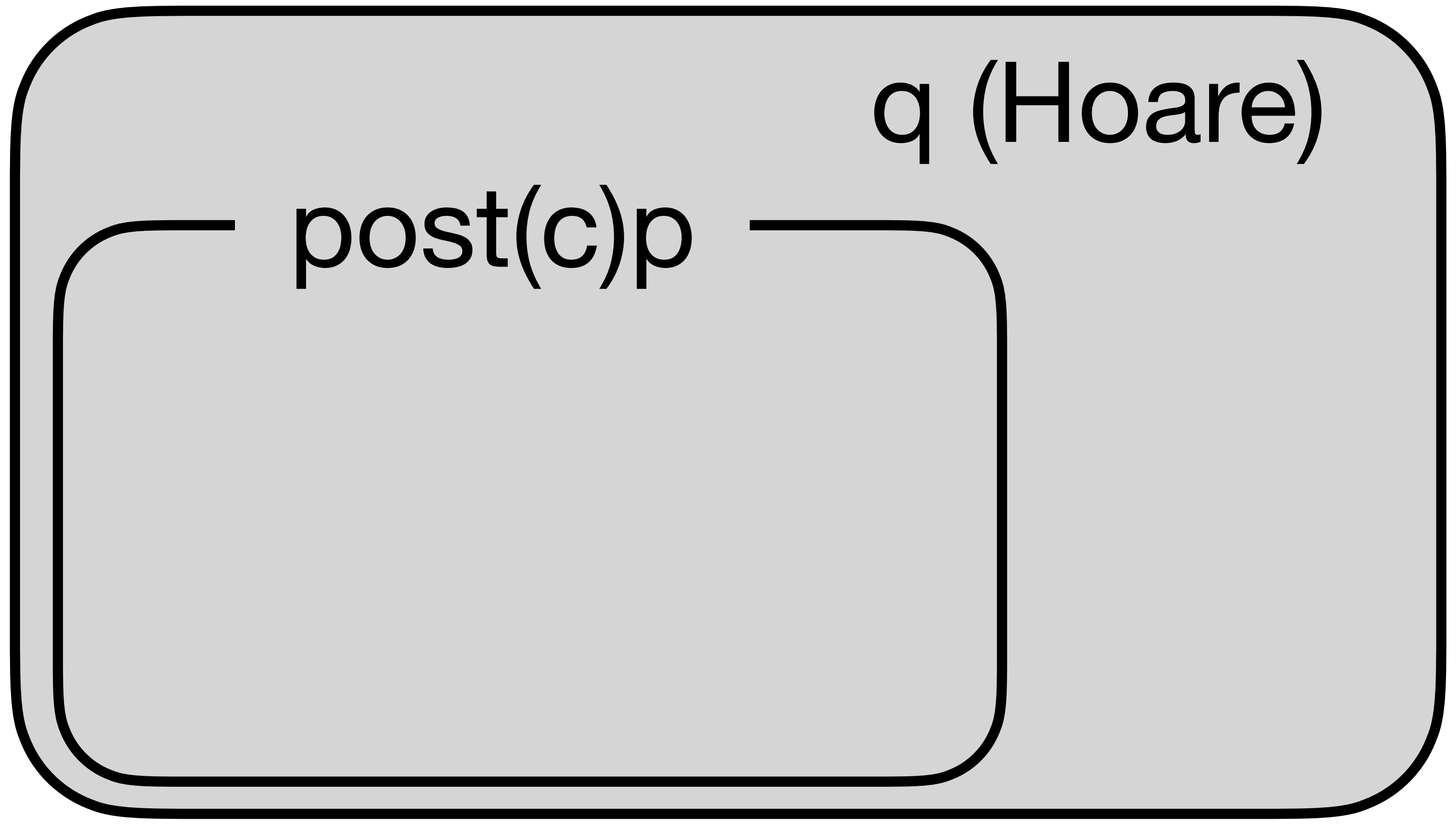

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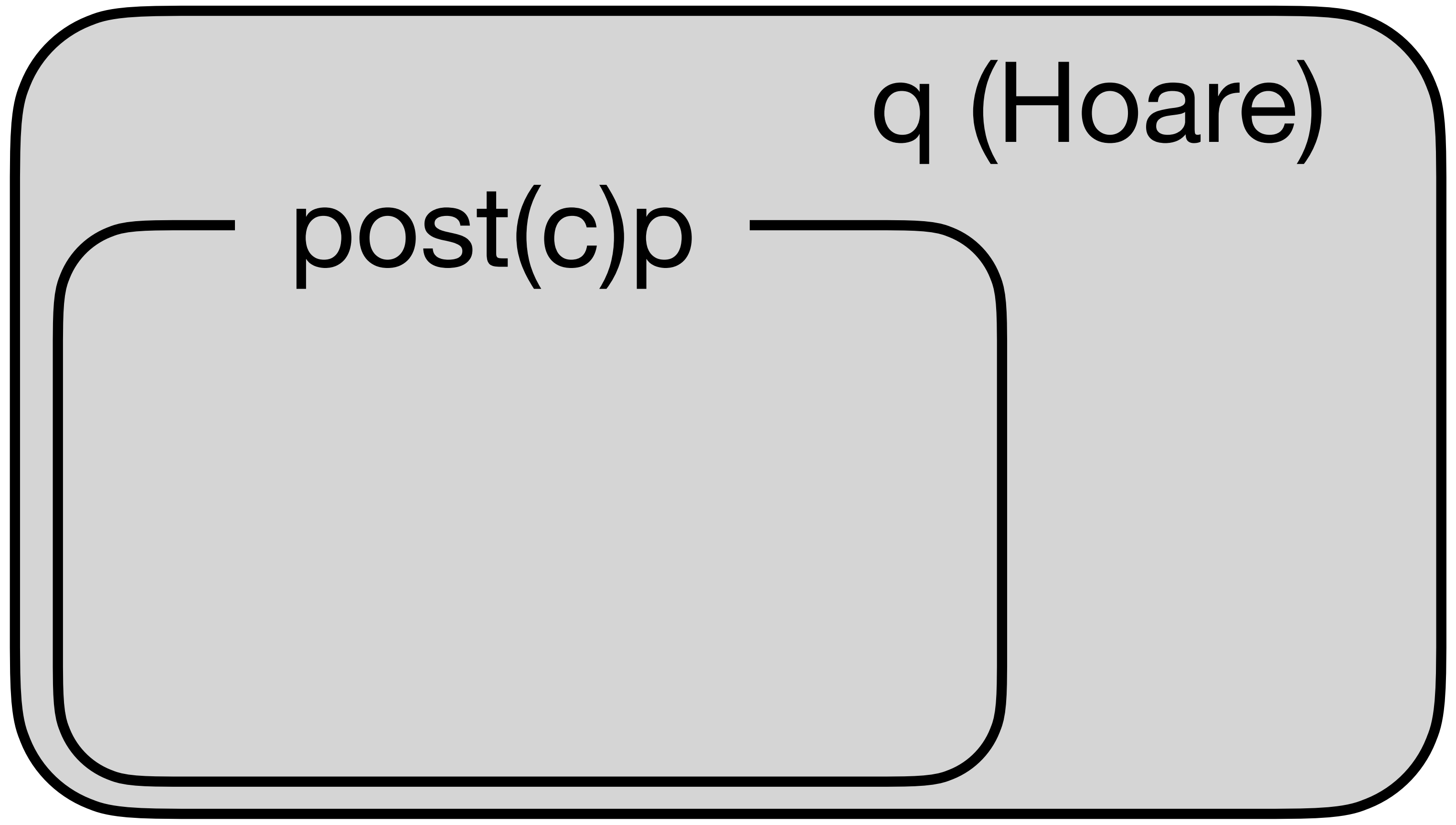

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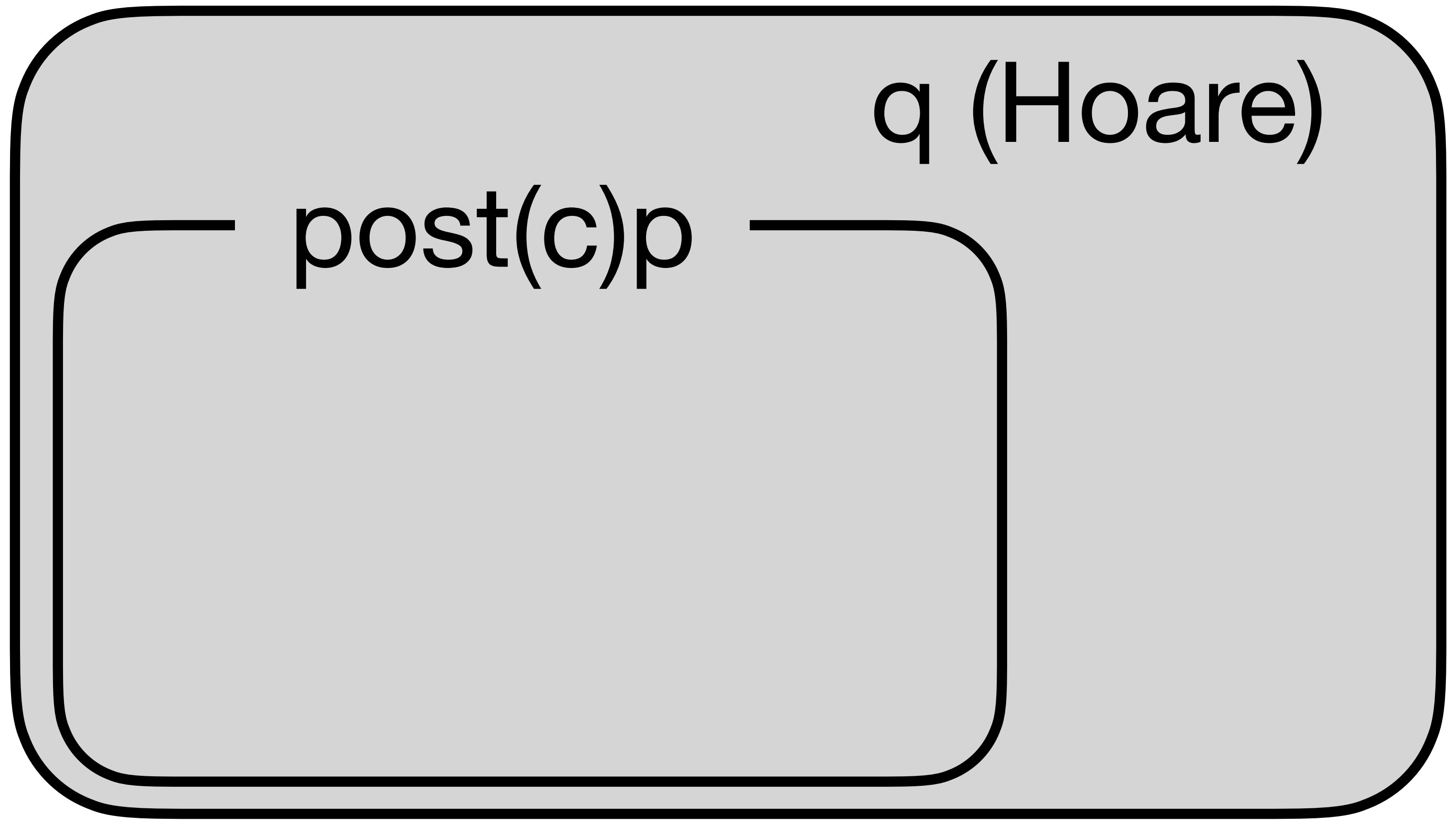

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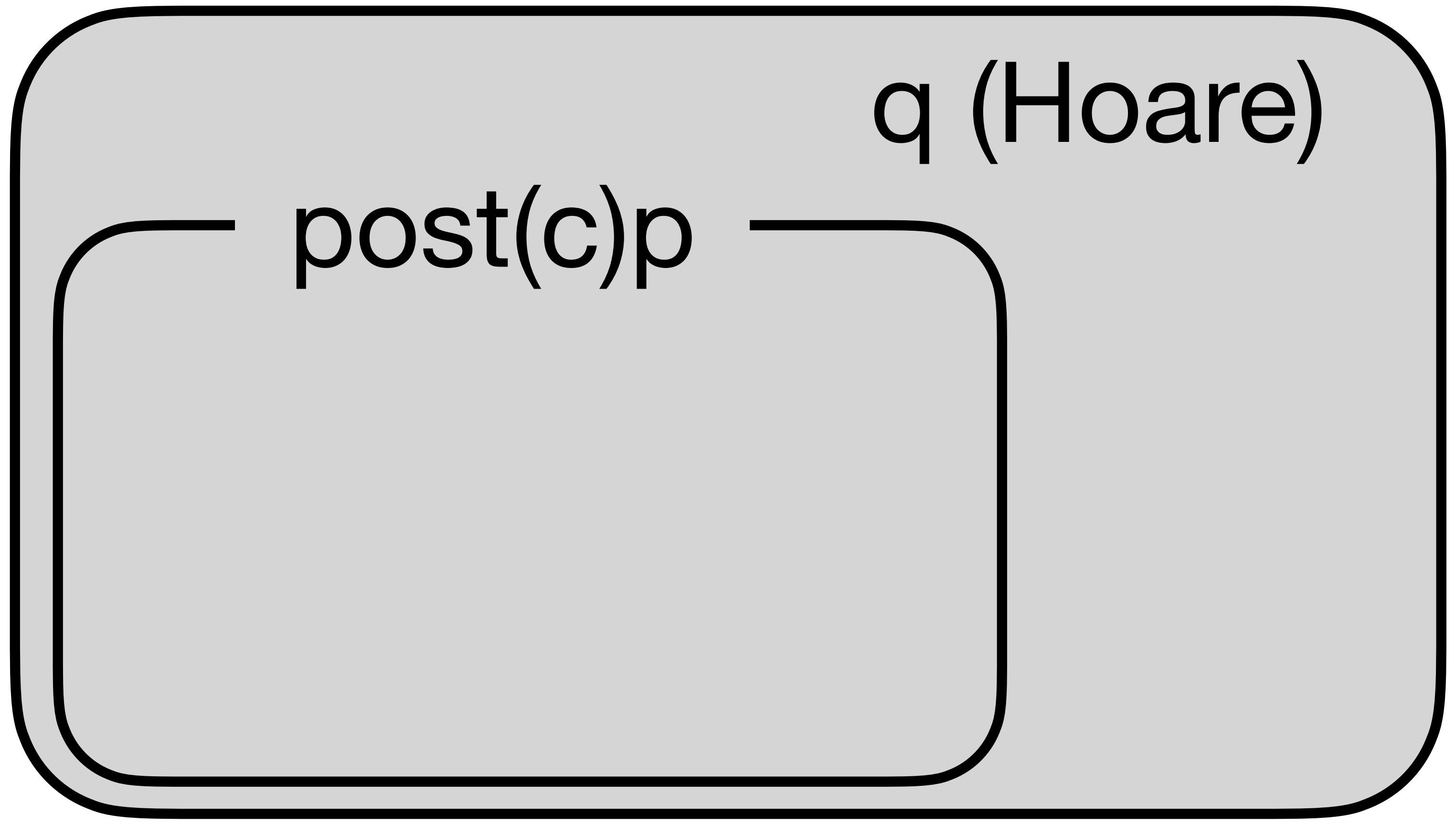

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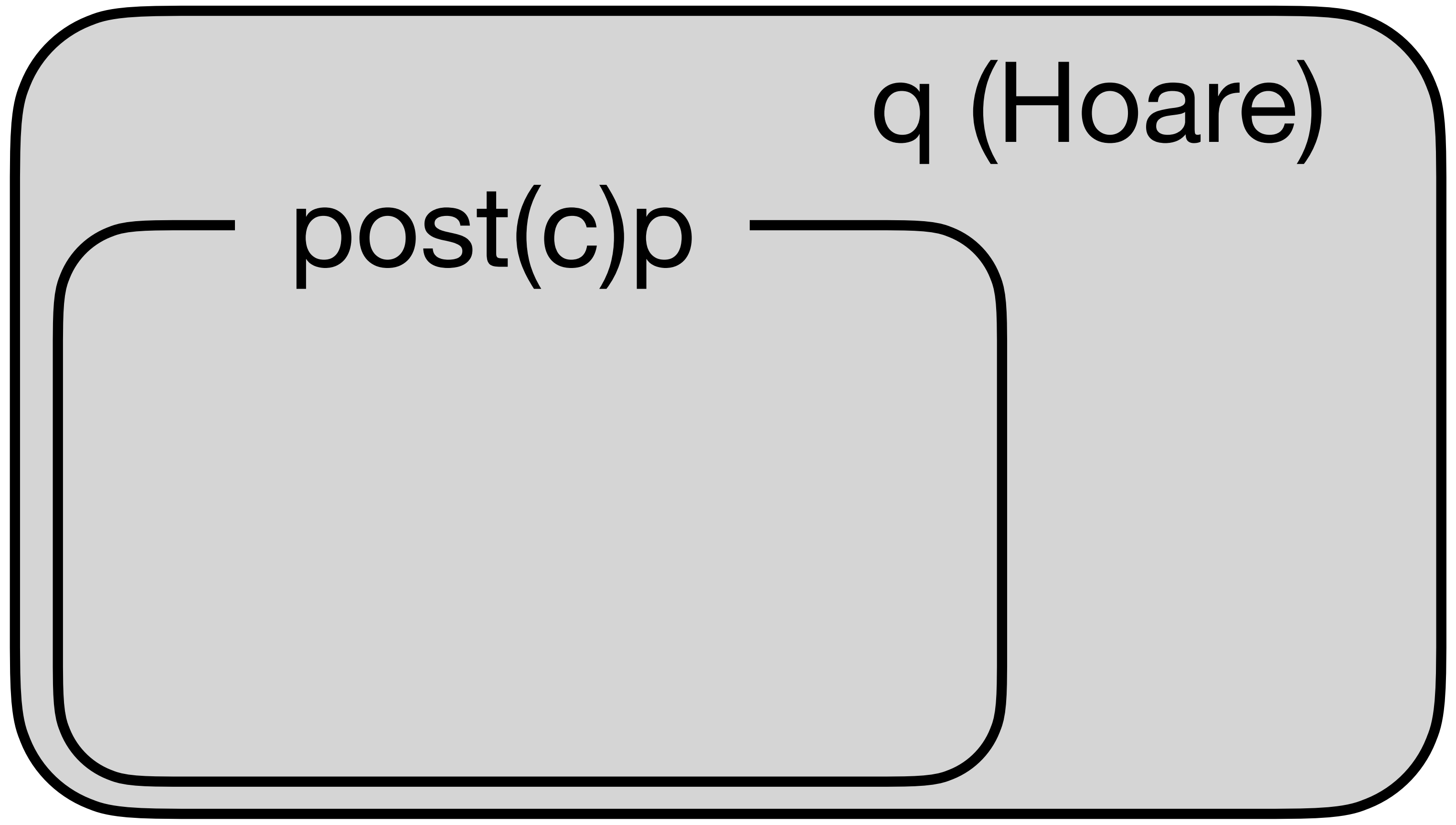

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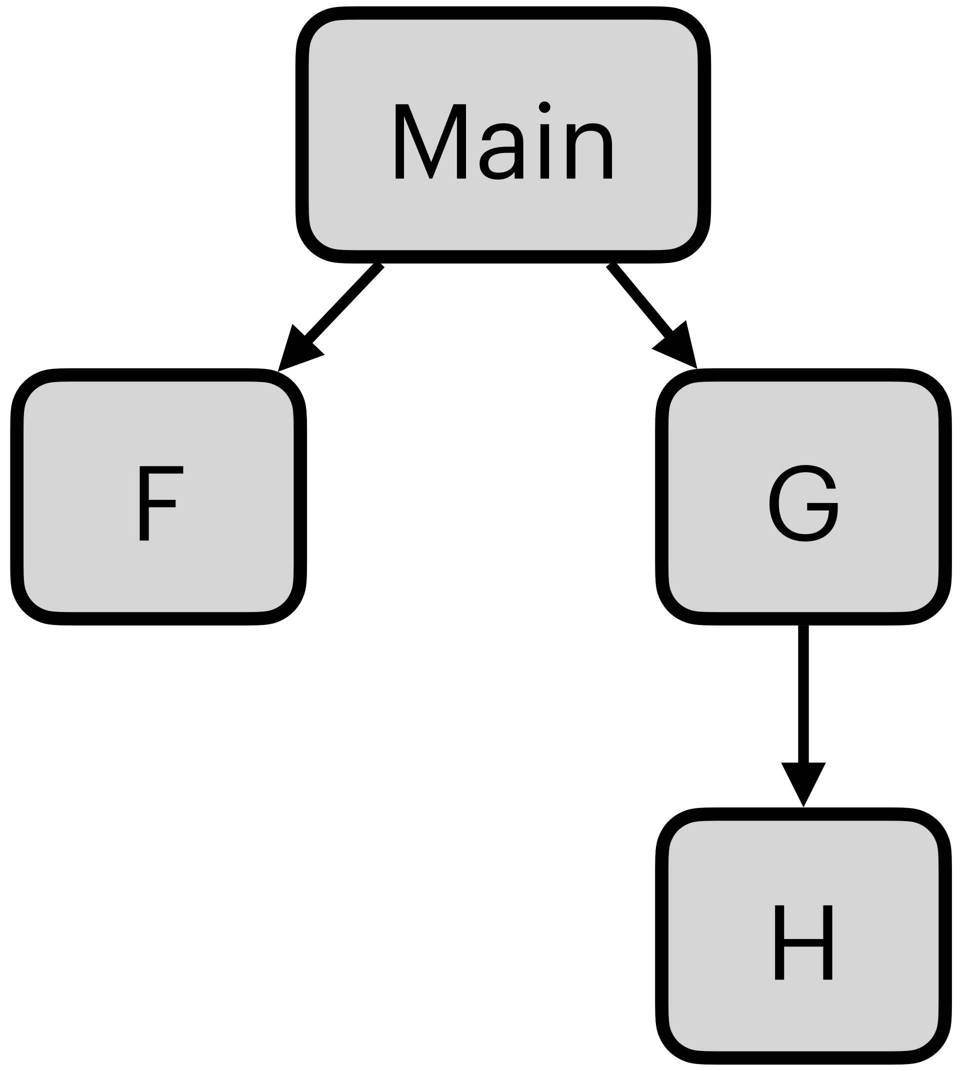

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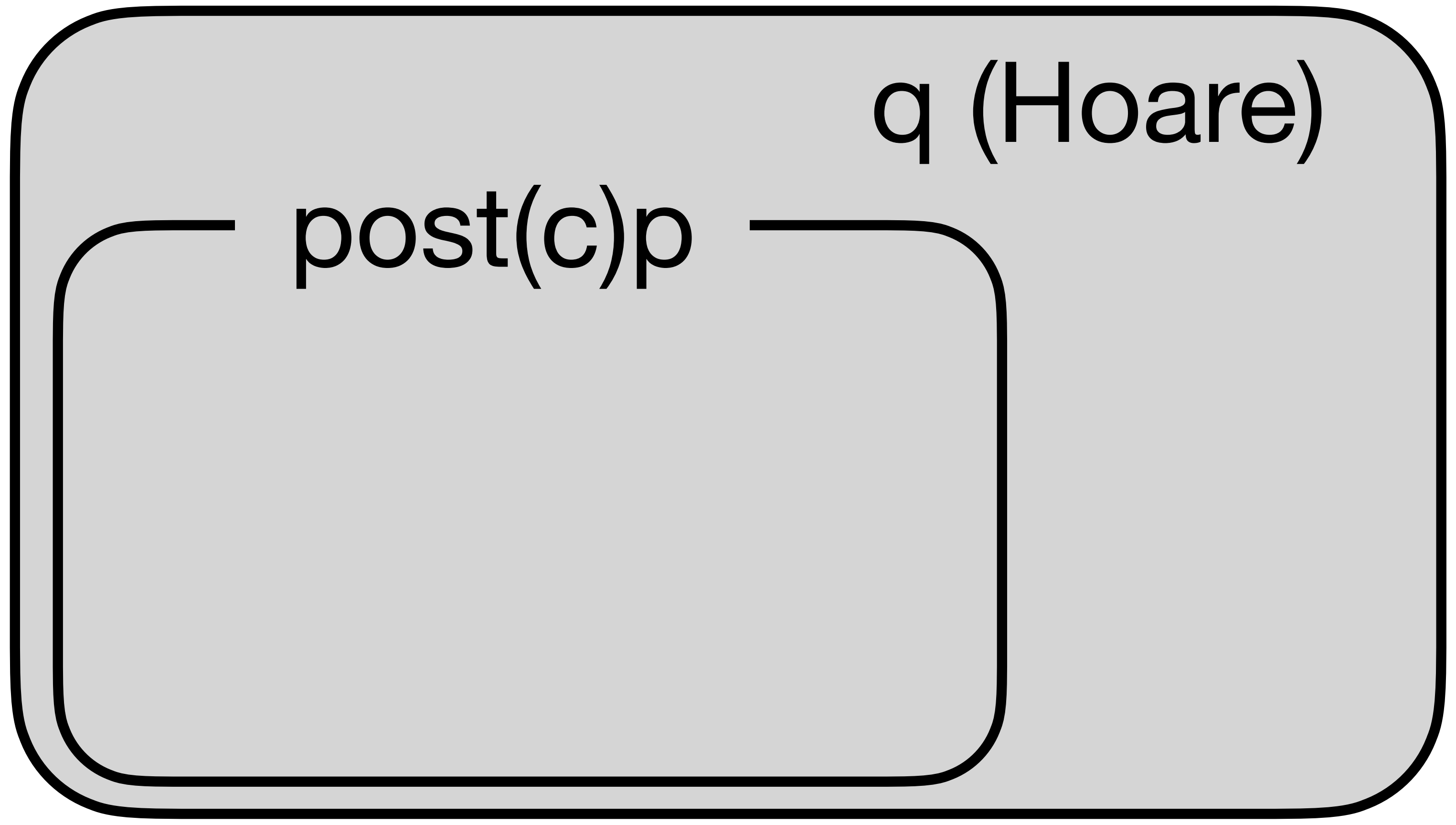

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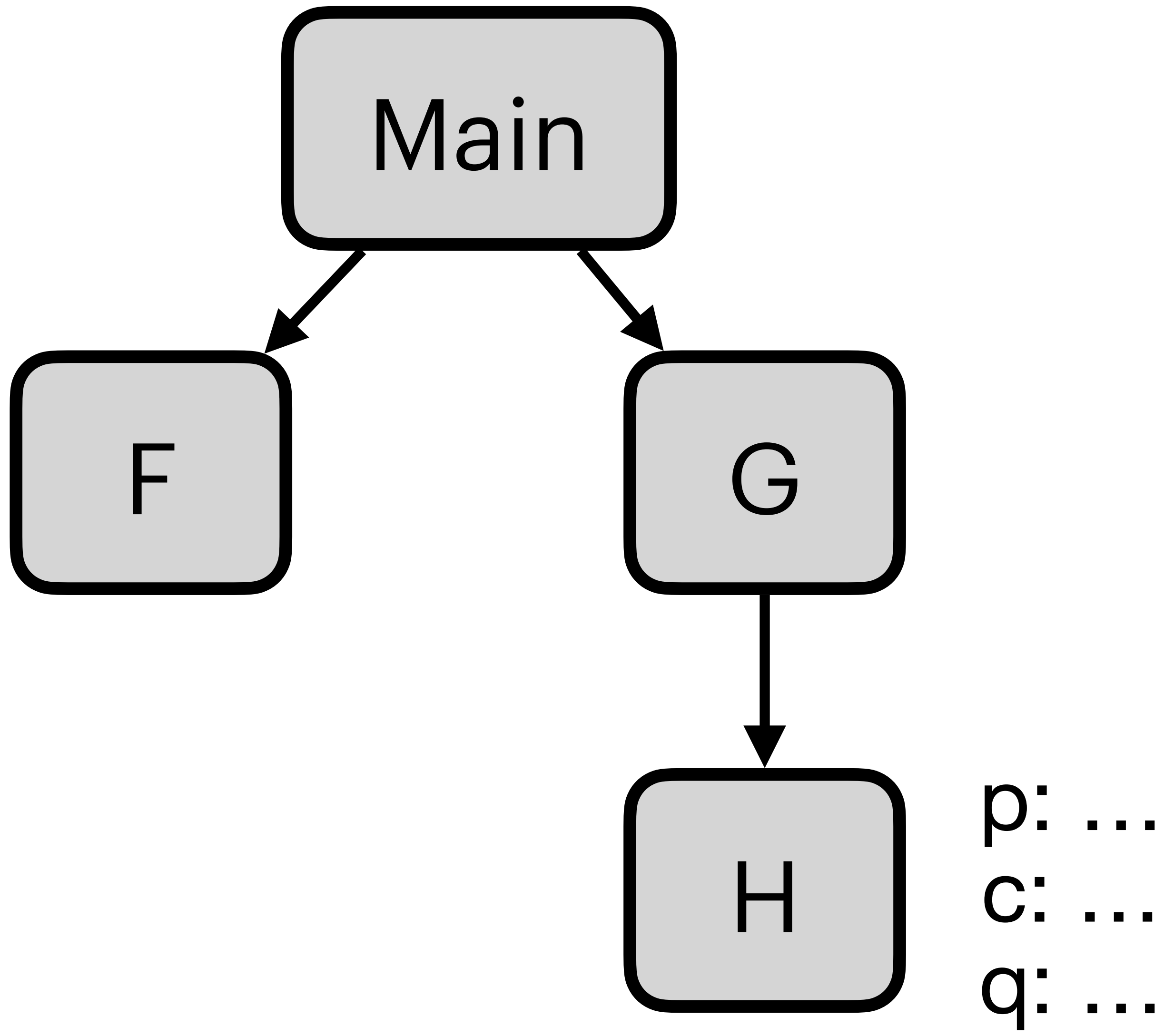

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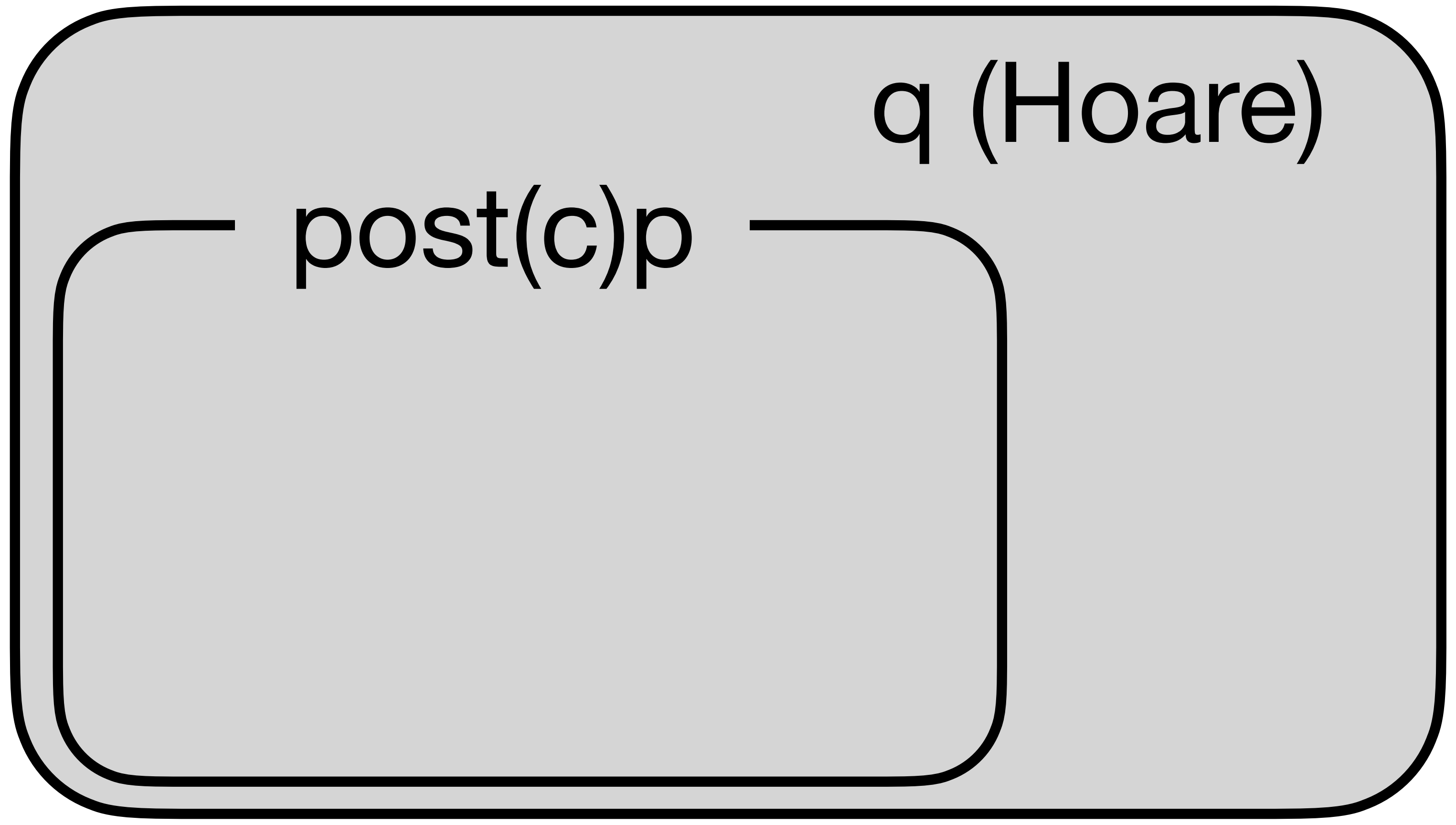

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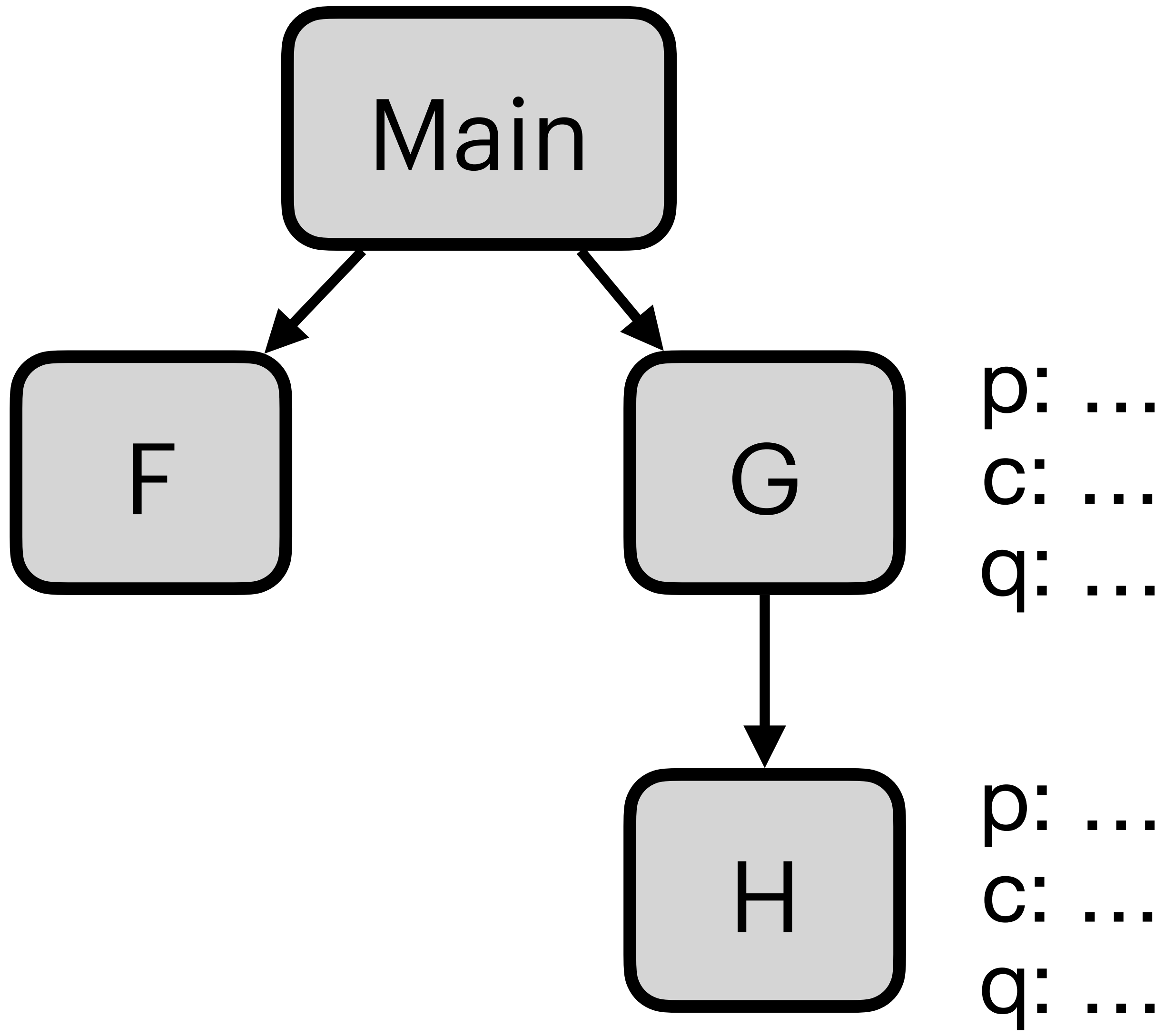

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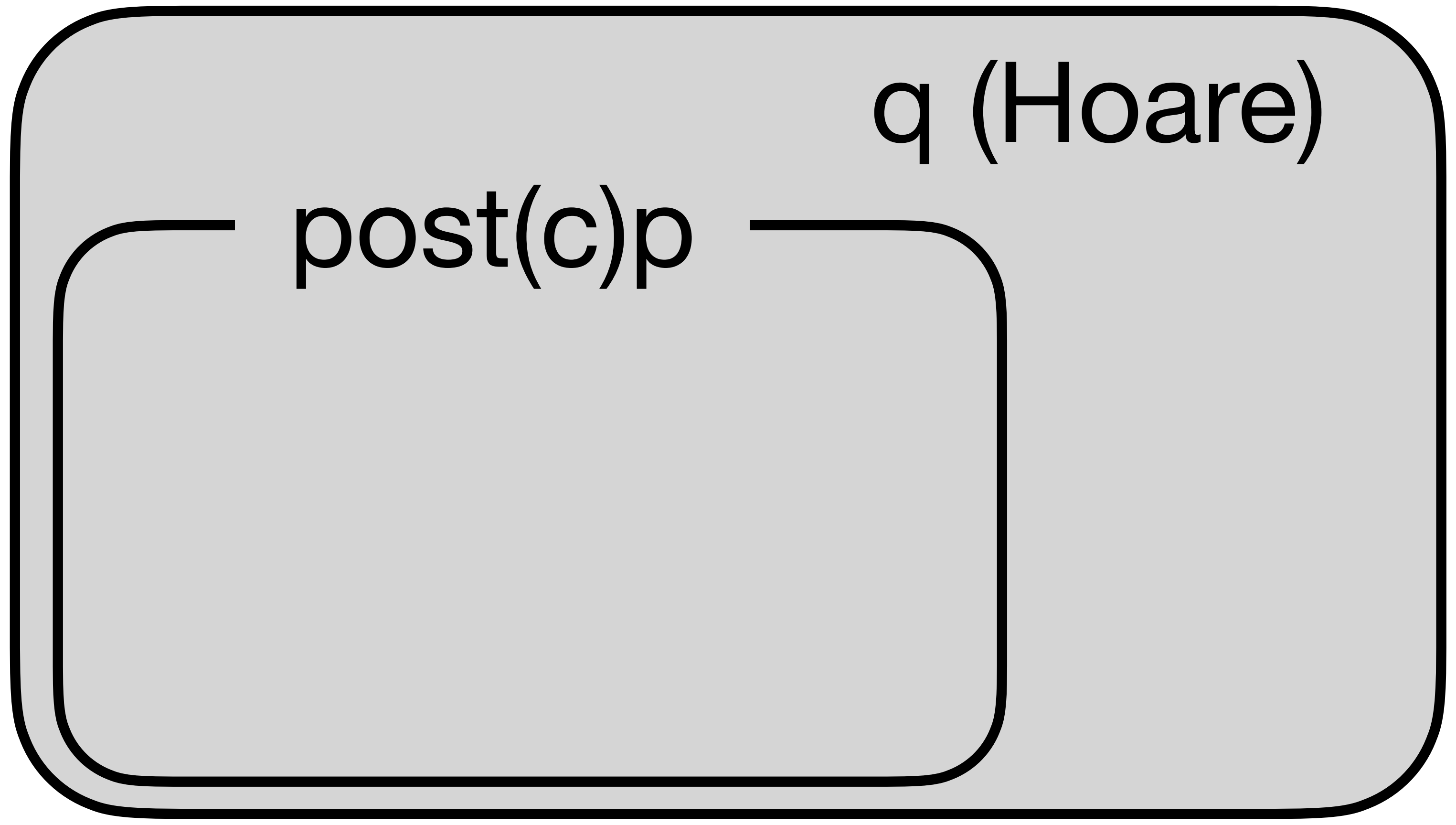

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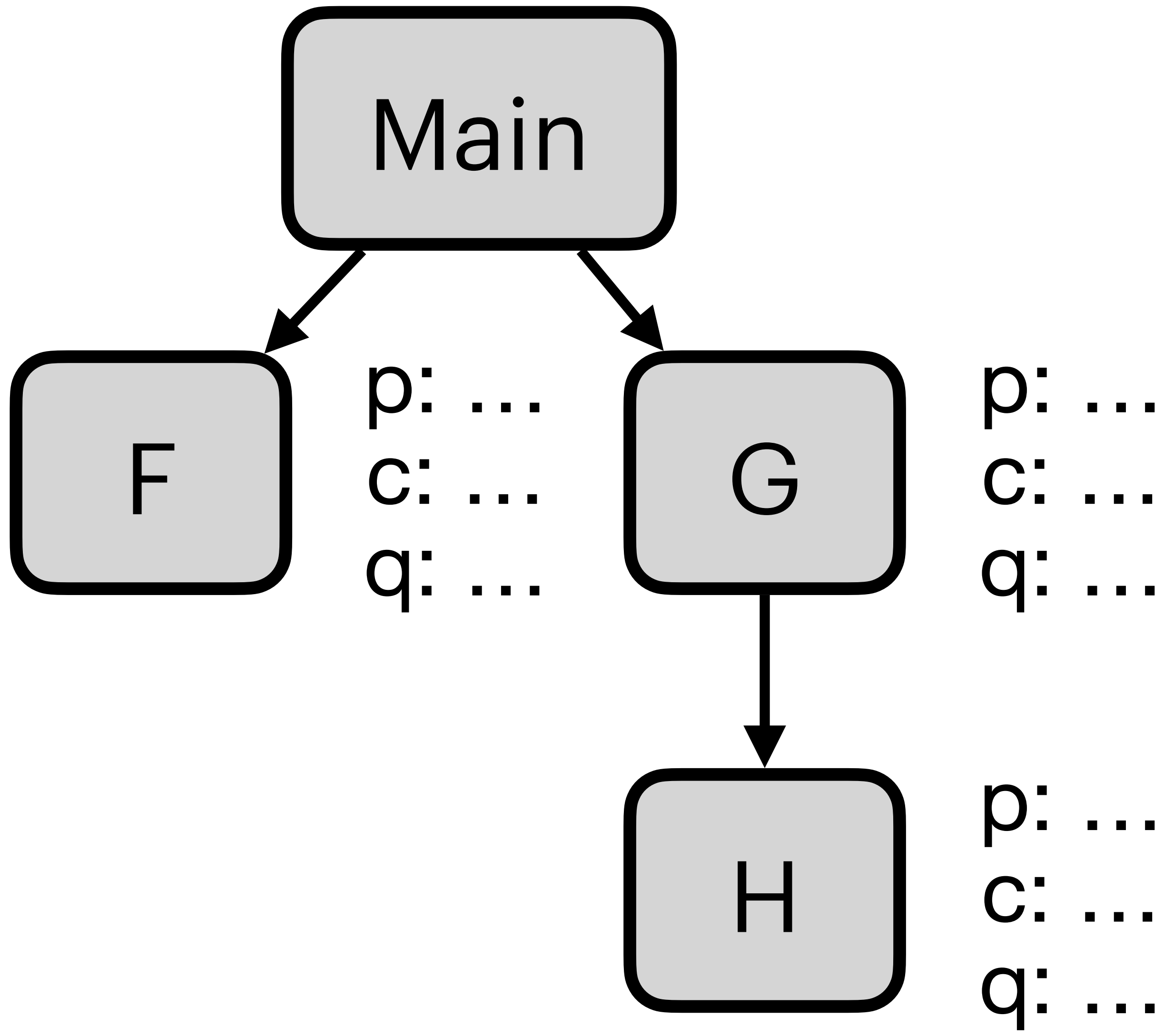

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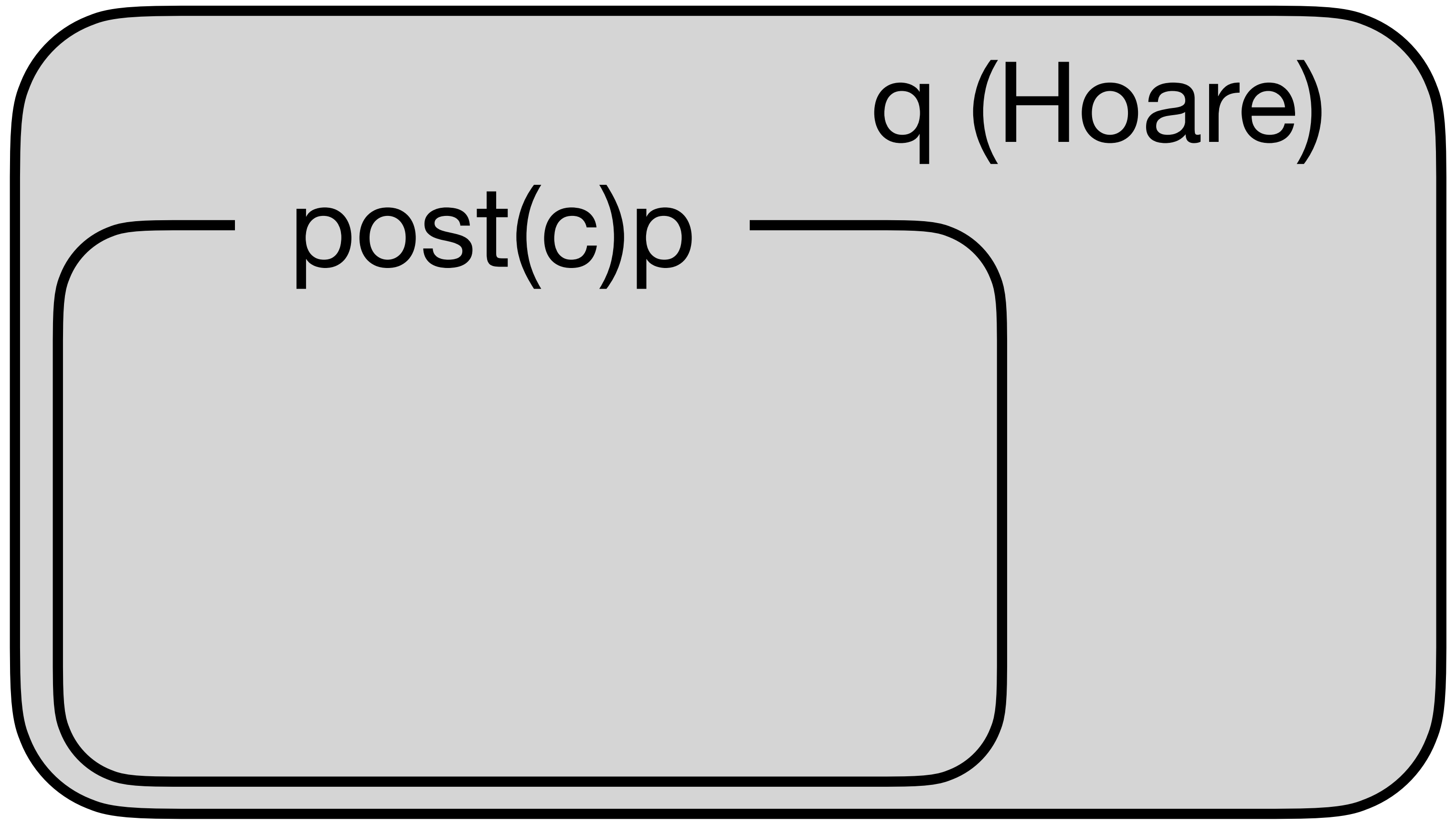

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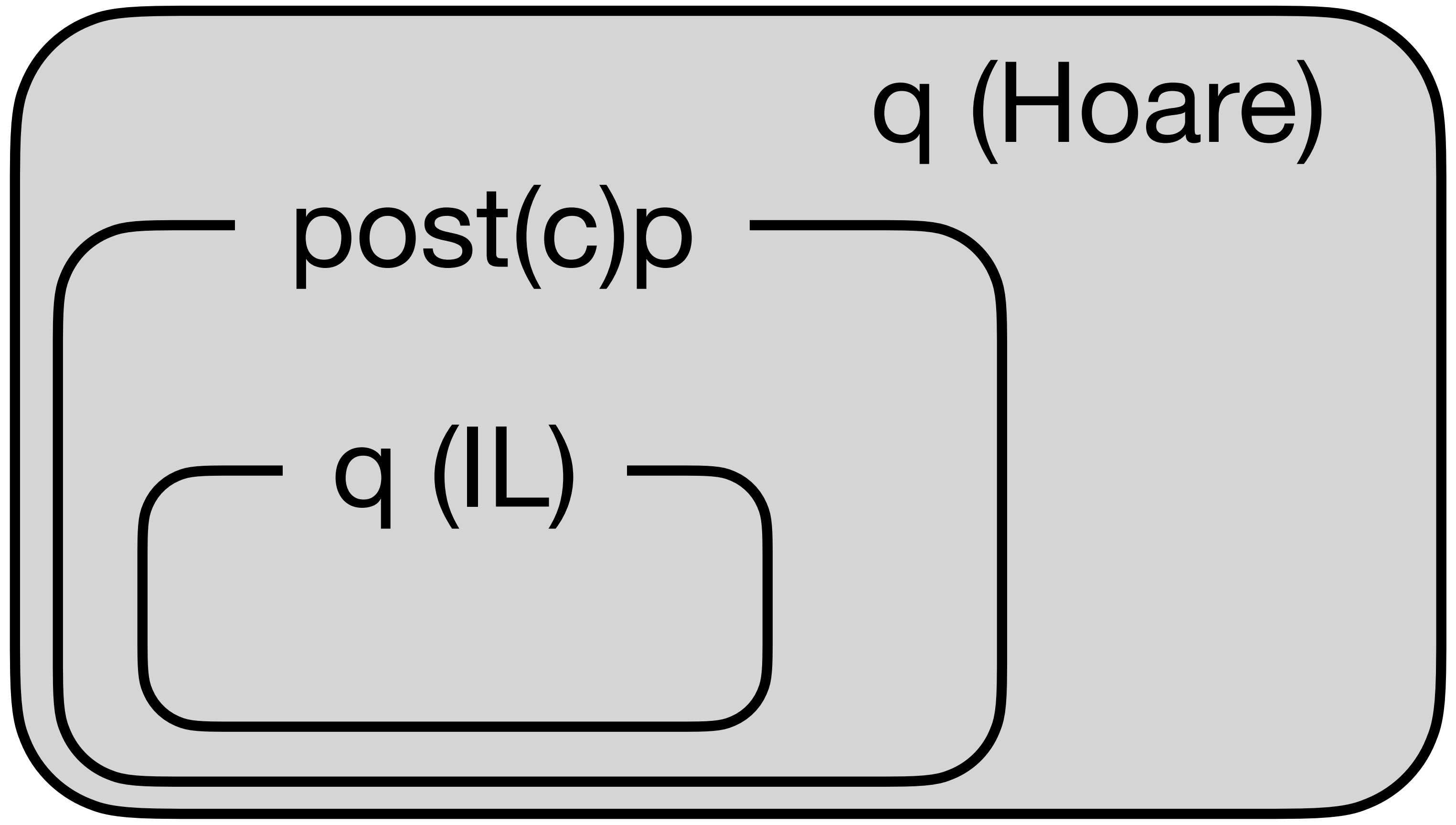

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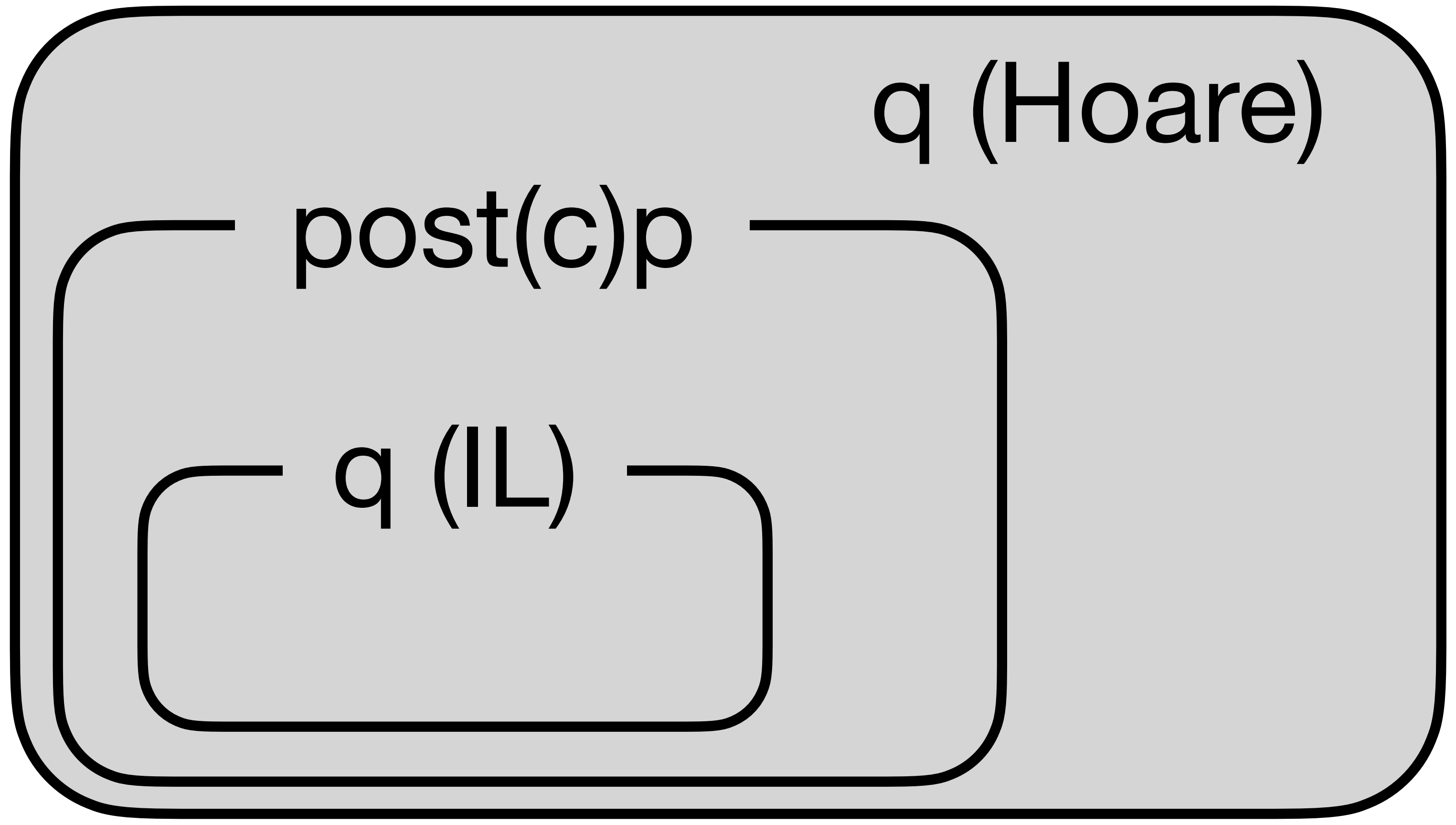

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- Add label ($\epsilon \in \{er, ok\}$) to results such that, $[p]c[\epsilon : q]$

$$\left[(\mathop{\ast}_{x_i \in \mathrm{pvars}(\pi)} x_i \mapsto X_i) \land \pi[\overrightarrow{X_i}/\overrightarrow{x_i}]\right] \; \texttt{assume}(\pi) \; \left[ok\colon (\mathop{\ast}_{x_i \in \mathrm{pvars}(\pi)} x_i \mapsto X_i) \land \pi[\overrightarrow{X_i}/\overrightarrow{x_i}]\right]$$

$$\left[\begin{array}{l}(\mathop{\ast}_{y_i \in \mathrm{pvars}(e)\setminus\{x\}} y_i \mapsto Y_i \ast x \mapsto X) \\ \land\, V = e[\overrightarrow{Y_i}/\overrightarrow{y_i}][X/x]\end{array}\right] \; x := e \; \left[ok\colon \begin{array}{l}(\mathop{\ast}_{y_i \in \mathrm{pvars}(e)\setminus\{x\}} y_i \mapsto Y_i \ast x \mapsto V) \\ \land\, V = e[\overrightarrow{Y_i}/\overrightarrow{y_i}][X/x]\end{array}\right]$$

$$[x \mapsto X \ast X \mapsto V \ast y \mapsto Y] \; [x] := y \; [ok\colon x \mapsto X \ast X \mapsto Y \ast y \mapsto Y]$$

$$[x \mapsto X \ast y \mapsto Y \ast Y \mapsto V] \; x := [y] \; [ok\colon x \mapsto V \ast y \mapsto Y \ast Y \mapsto V]$$

$$[\mathsf{emp}] \; \texttt{skip} \; [ok\colon \mathsf{emp}] \qquad [\mathsf{emp}] \; \texttt{error()} \; [er\colon \mathsf{emp}]$$

$$[x \mapsto X \ast X \not\mapsto] \; [x] := y \; [er\colon x \mapsto X \ast X \not\mapsto] \qquad [y \mapsto Y \ast Y \not\mapsto] \; x := [y] \; [er\colon y \mapsto Y \ast Y \not\mapsto]$$

$$[x \mapsto X \land X = \mathsf{nil}] \; [x] := y \; [er\colon x \mapsto X \land X = \mathsf{nil}] \qquad [y \mapsto Y \land Y = \mathsf{nil}] \; x := [y] \; [er\colon y \mapsto Y \land Y = \mathsf{nil}]$$

$$[x \mapsto X \ast X \mapsto V] \; \texttt{free}(x) \; [ok\colon x \mapsto X \ast X \not\mapsto] \qquad [x \mapsto X] \; x := \texttt{malloc()} \; [ok\colon \exists L.\, x \mapsto L \ast L \mapsto V \land \mathsf{true}]$$

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$$[x \mapsto X \land X = \mathsf{nil}] \; \texttt{free}(x) \; [er\colon x \mapsto X \land X = \mathsf{nil}] \qquad [x \mapsto X \ast \mathsf{ret} \mapsto V] \; \texttt{return}(x) \; [ok\colon x \mapsto X \ast \mathsf{ret} \mapsto X]$$

Fig. 3. Predefined Pulse-X summaries as ISL triples, where pvars(.) returns the program variables of an expression or a statement; for brevity, we omit the pure assertion true and write p in lieu of $p \land \mathsf{true}$.

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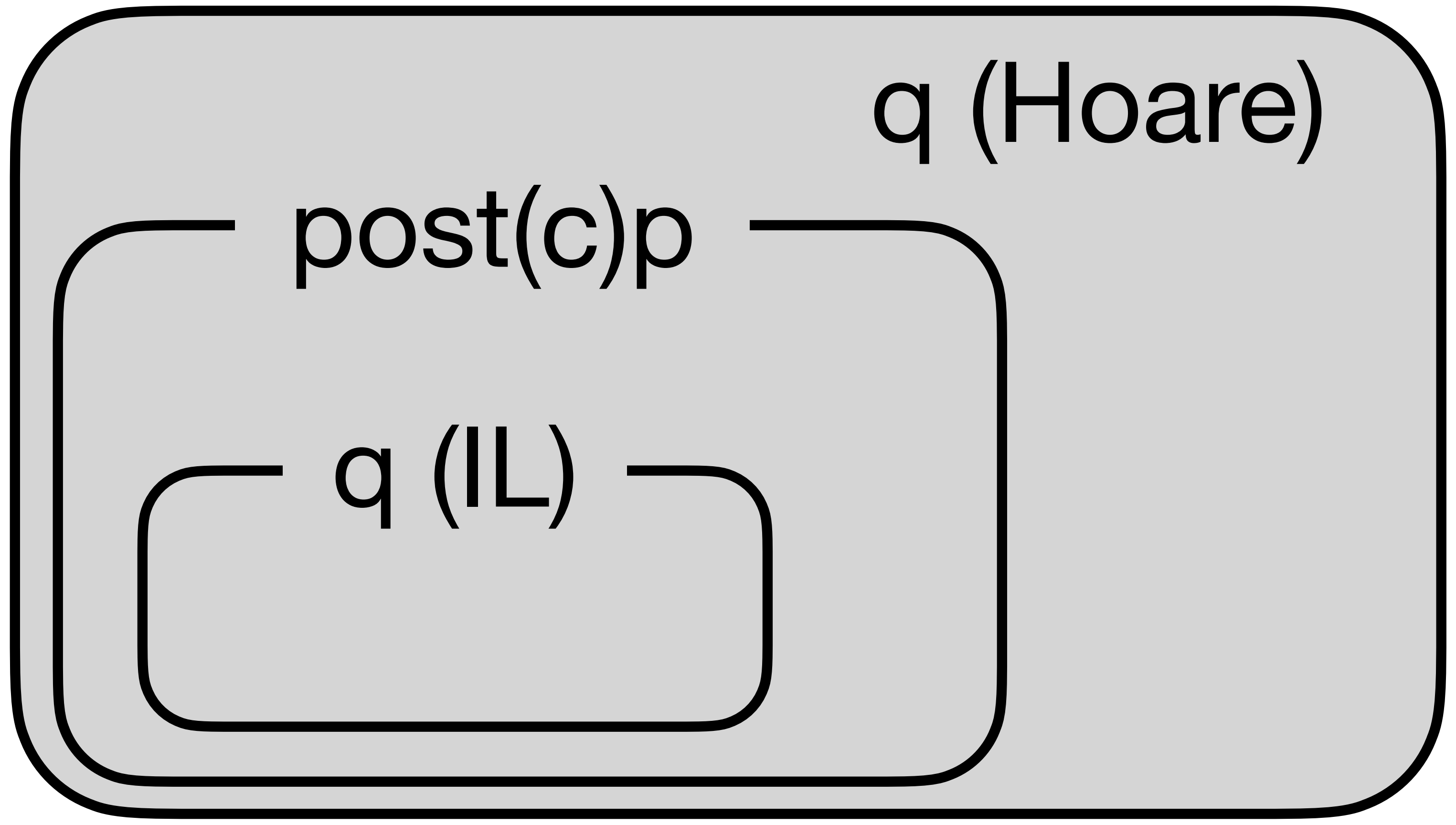

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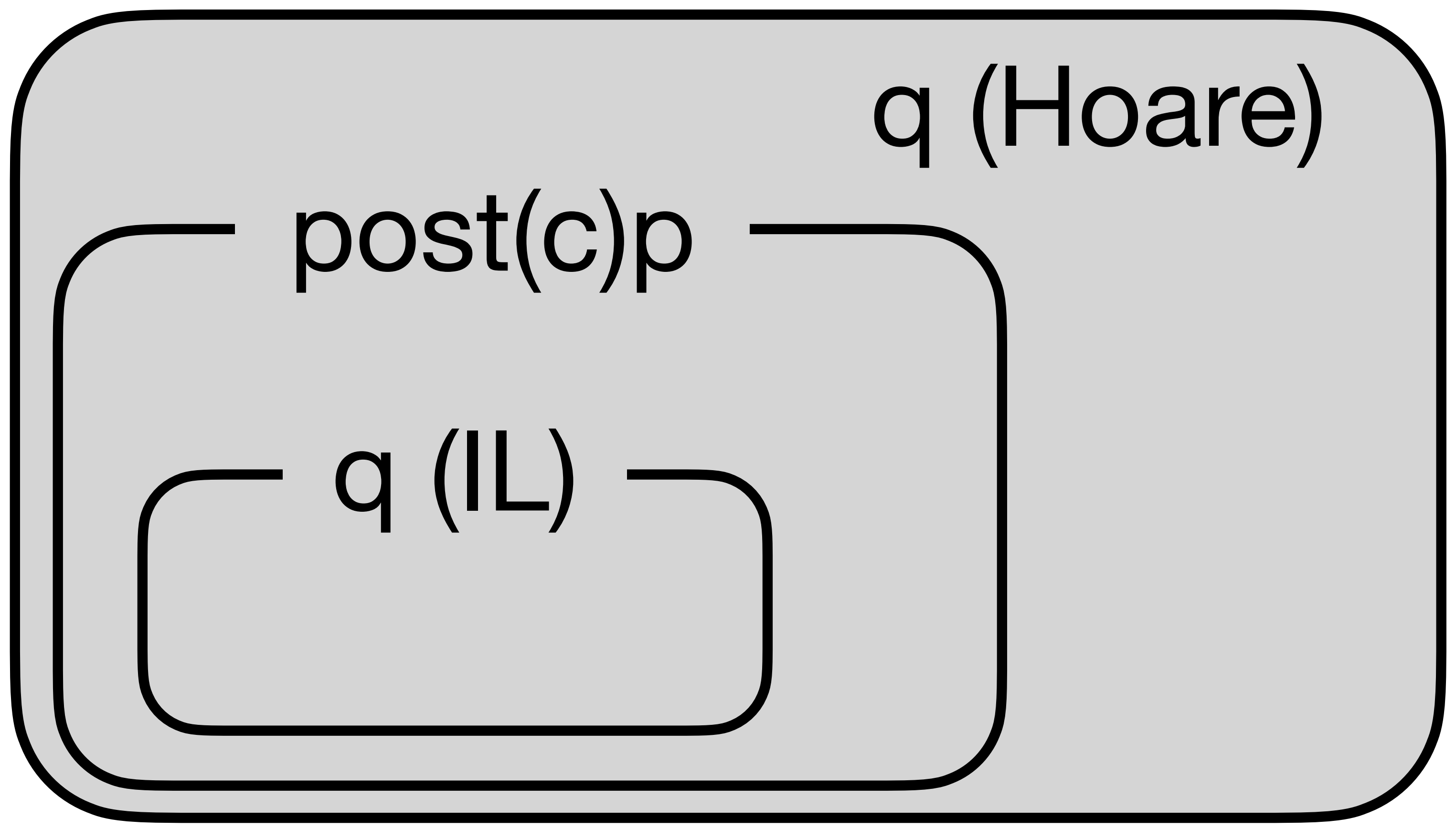

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void f (int* x) {
  *x = 42;
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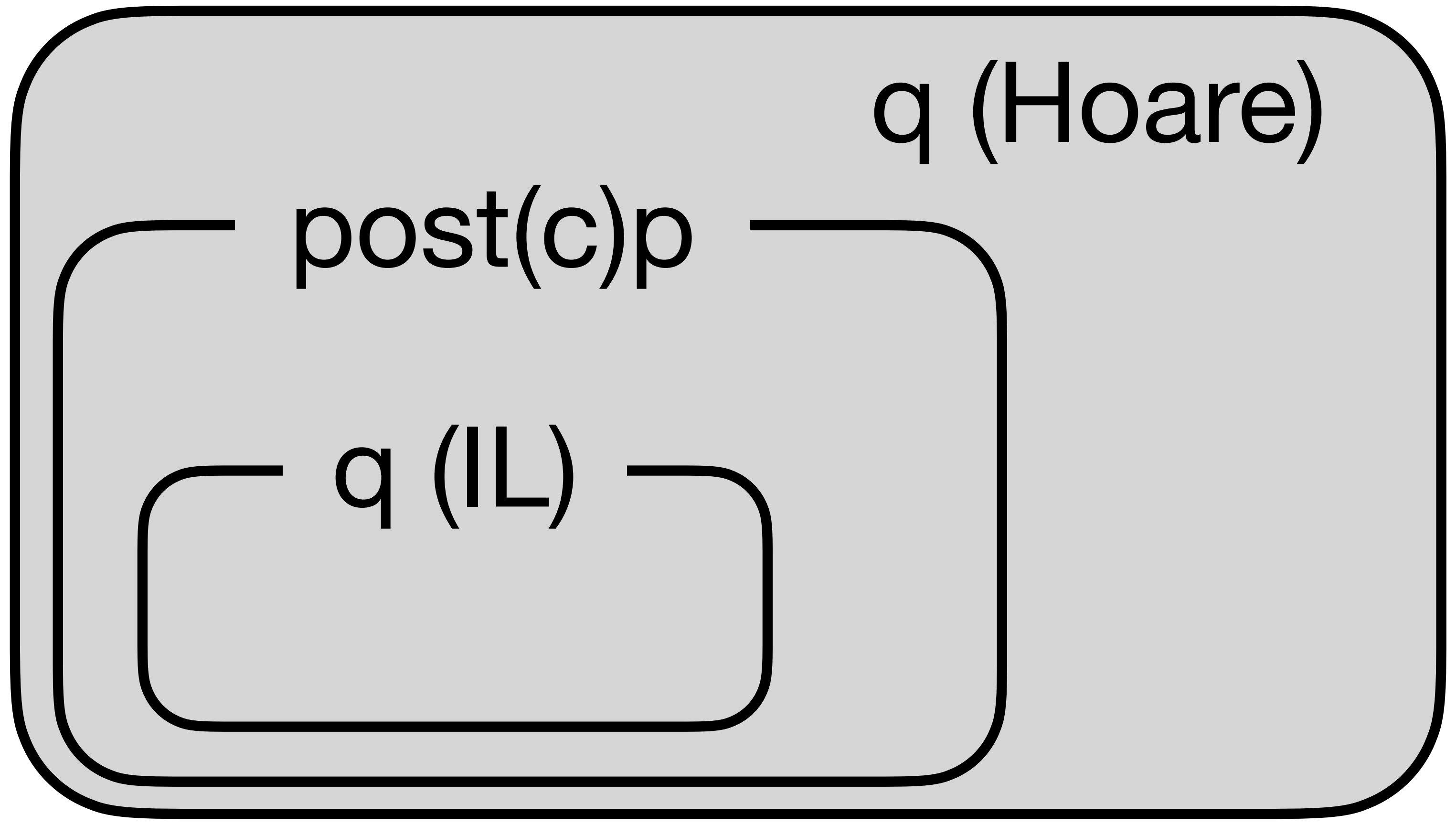

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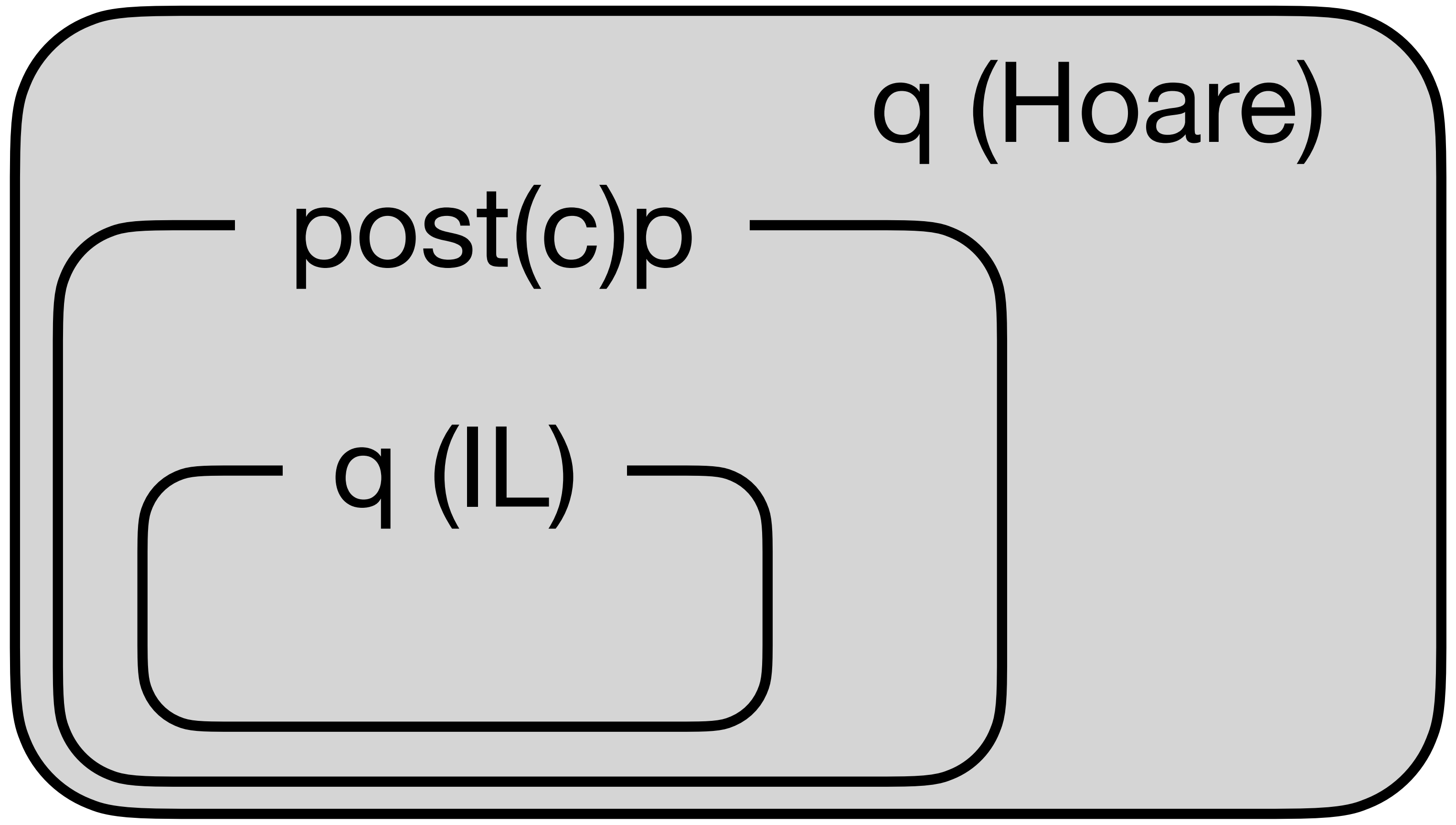

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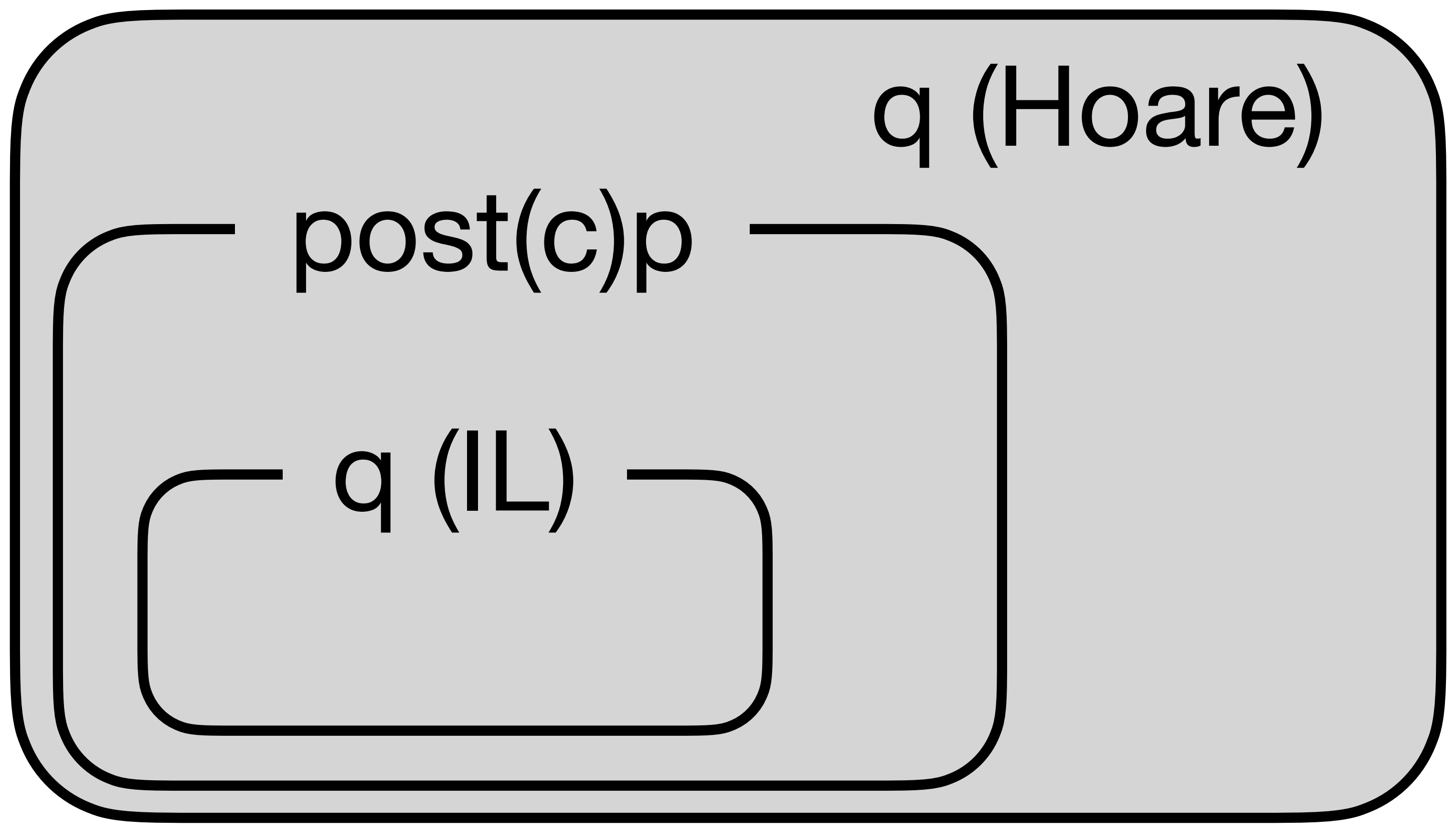

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- Another precision filter for the alarms

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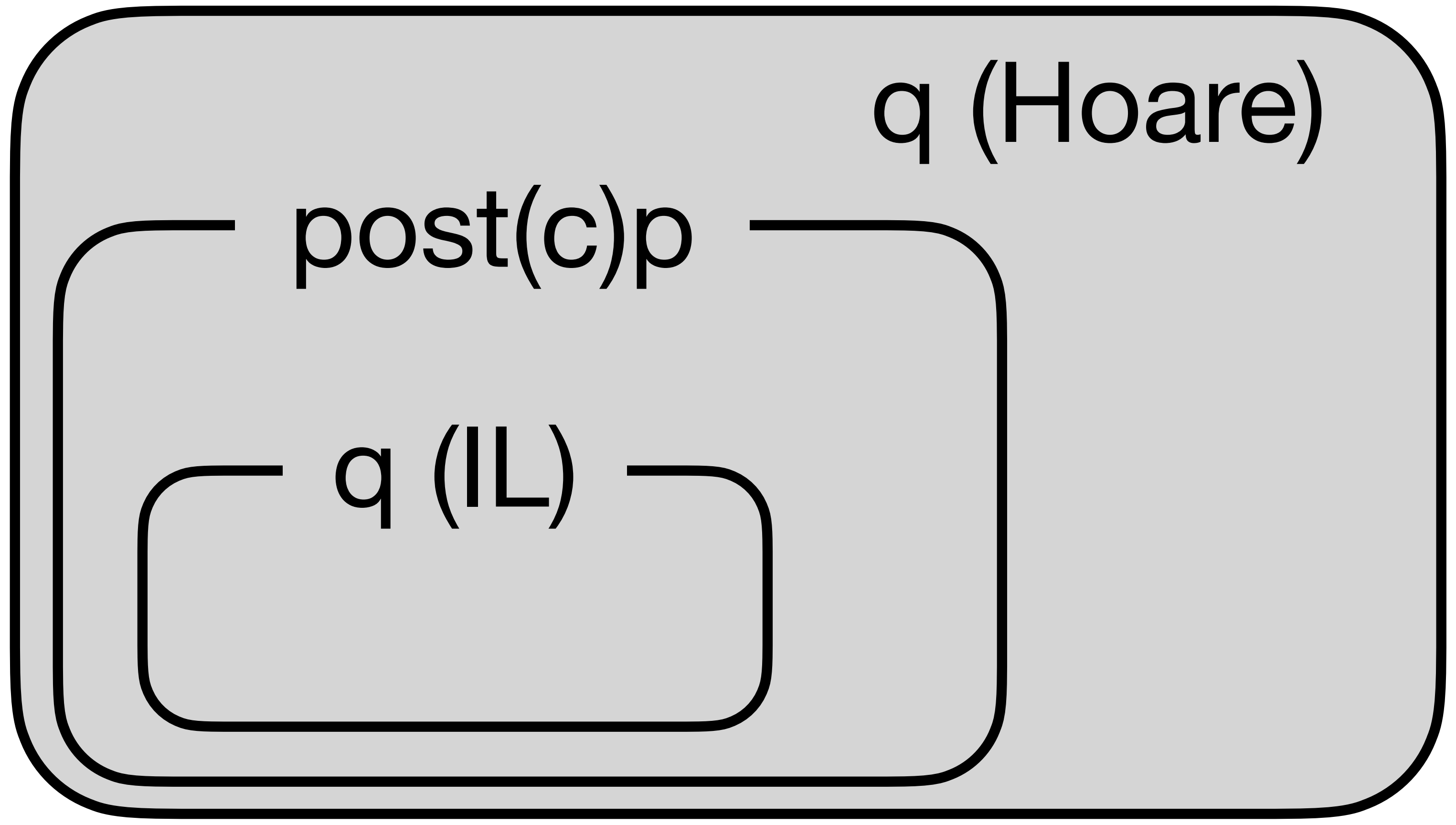

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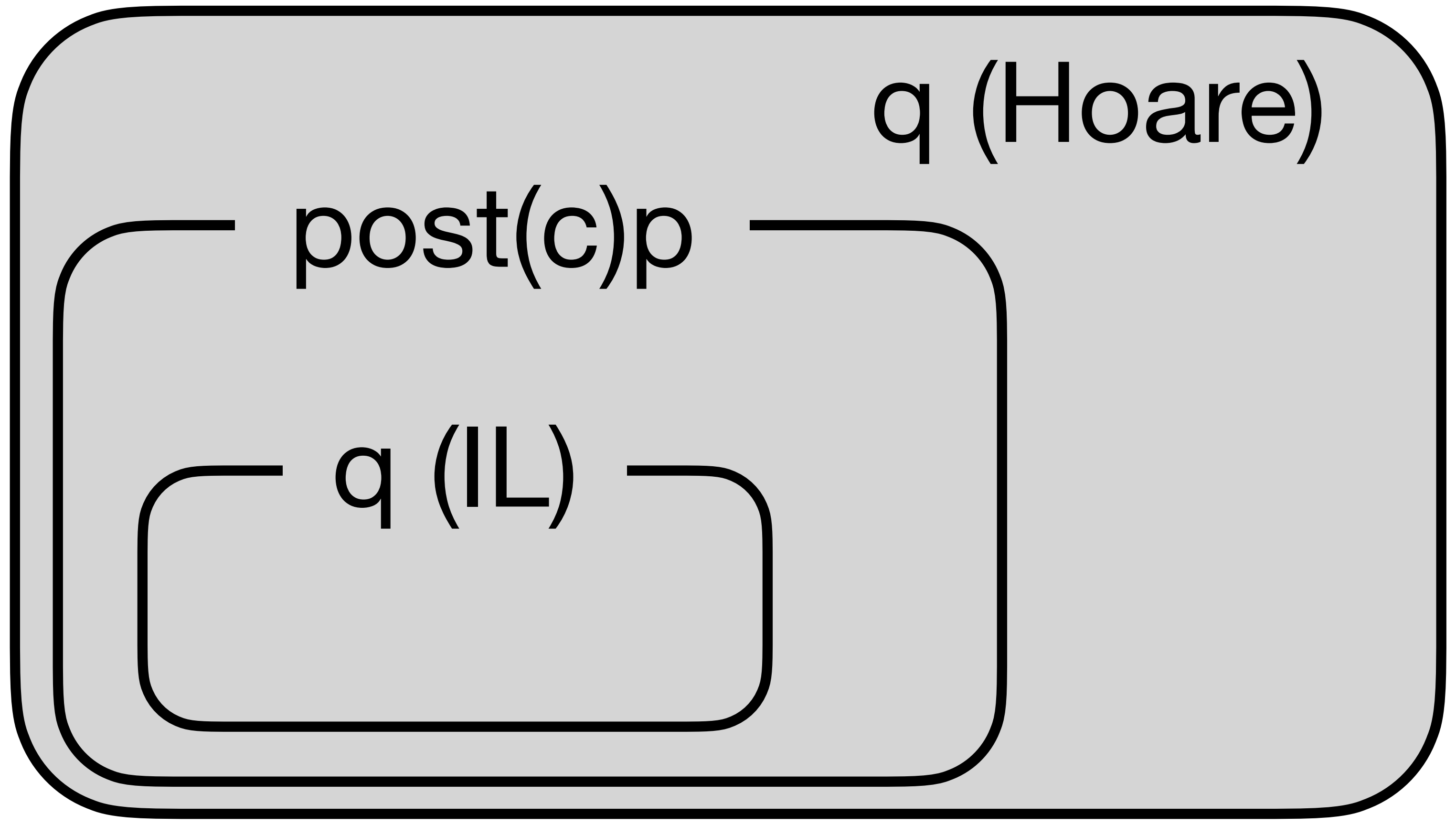

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- Another precision filter for the alarms
- Manifest bugs: any call to the function triggers the bug
- Latent Bugs: some call to the function triggers the bug

Pulse-X: example 1

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```
int ssl_excert_prepend(SSL_EXCERT **pexc) {
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  memset(exc, 0, sizeof(*exc));
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Manifest Bug: no matter the caller, it will always trigger the Bug

Pulse-X: example 2

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```
int chopup_args(ARGS *arg, char *buf, int *argc, char **argv[]) {
  int num, i;
  ...
  if (arg->count == 0) {
    arg->count = 20;
    arg->data = (char**)OPENSSL_malloc( sizeof(char*) * arg->count);
  }
 for (i=0; i<arg->count; i++)
   arg->data[i] = NULL;
...
}
```

Pulse-X: example 2

```
int chopup_args(ARGS *arg, char *buf, int *argc, char **argv[]) {
  int num, i;
  ...
  if (arg->count == 0) {
    arg->count = 20;
    arg->data = (char**)OPENSSL_malloc( sizeof(char*) * arg->count);
  }
 for (i=0; i<arg->count; i++)
   arg->data[i] = NULL;
...
}
```

Pulse-X: example 2

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int chopup_args(ARGS *arg, char *buf, int *argc, char **argv[]) {
  int num, i;
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Pulse-X: example 2

```
1. int chopup_args(ARGS *arg, char *buf, int *argc, char **argv[]) {
2.   int num, i;
3.   ...
4.   if (arg->count == 0) {
5.     arg->count = 20;
6.     arg->data = (char**)OPENSSL_malloc( sizeof(char*) * arg->count);
7.   }
8.  for (i=0; i<arg->count; i++)
9.    arg->data[i] = NULL;
10. ...
11. }
```

Latent Bug: Bug triggered only if condition on line 4 is satisfied

Pulse-X: example 3

```
int main(int *argc, char **argv[]) {
  ...
  arg.count=0
  ...
  if( !chopop_args(&arg, buf, &argc,&argv)) break;
}
```

Pulse-X: example 3

```
int main(int *argc, char **argv[]) {
    ...
    arg.count=0
    ...
    if( !chopop_args(&arg, buf, &argc,&argv)) break;
}
```

Pulse-X: example 3

```
int main(int *argc, char **argv[]) {
    ...
    arg.count=0
    ...
    if( !chopop_args(&arg, buf, &argc,&argv)) break;
}
```

Pulse-X: example 3

```
int main(int *argc, char **argv[]) {
  ...
  arg.count=0
  ...
  if( !chopop_args(&arg, buf, &argc,&argv)) break;
}
```

Manifest Bug: Bug triggered regardless of the caller

Evaluation

Evaluation

Goal

Evaluation

Goal

- Pulse-X is superior in fix-rate

Evaluation

Goal

- Pulse-X is superior in fix-rate
- Pulse-X can find new bugs

Evaluation

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Target Program

Evaluation

Goal

- Pulse-X is superior in fix-rate
- Pulse-X can find new bugs

Target Program

- OpenSSL

Evaluation

Goal

- Pulse-X is superior in fix-rate
- Pulse-X can find new bugs

Target Program

- OpenSSL
  - < 8000 functions, < 400K lines of code

Evaluation

Goal

- Pulse-X is superior in fix-rate
- Pulse-X can find new bugs

Target Program

- OpenSSL
  - < 8000 functions, < 400K lines of code
- Correct Bug: only if it is fixed

Fix Rate

Fix Rate

Pulse-X

Fix Rate

Pulse-X

- Total: 26 bugs

Fix Rate

Pulse-X

- Total: 26 bugs
- Fixed: 19 bugs

Fix Rate

Pulse-X

- Total: 26 bugs
- Fixed: 19 bugs
- Fix rate: 73%

Fix Rate

Pulse-X

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Infer

Fix Rate

Pulse-X

- Total: 26 bugs
- Fixed: 19 bugs
- Fix rate: 73%

Infer

- Total: 80 bugs

Fix Rate

Pulse-X

- Total: 26 bugs
- Fixed: 19 bugs
- Fix rate: 73%

Infer

- Total: 80 bugs
- Fixed: 39 bugs

Fix Rate

Pulse-X

- Total: 26 bugs
- Fixed: 19 bugs
- Fix rate: 73%

Infer

- Total: 80 bugs
- Fixed: 39 bugs
- Fix rate: 50%

Fix Rate

Pulse-X

- Total: 26 bugs
- Fixed: 19 bugs
- Fix rate: 73%

Pulse-X has better fix rate!

Infer

- Total: 80 bugs
- Fixed: 39 bugs
- Fix rate: 50%

New Bugs

On recent version of OpenSSL

New Bugs

On recent version of OpenSSL

Pulse-X

New Bugs

On recent version of OpenSSL

Pulse-X

- Total: 30 bugs

New Bugs

On recent version of OpenSSL

Pulse-X

- Total: 30 bugs
- Fixed: 15 bugs

New Bugs

On recent version of OpenSSL

Pulse-X

- Total: 30 bugs
- Fixed: 15 bugs
- Pending: 5 bugs

New Bugs

On recent version of OpenSSL

Pulse-X

- Total: 30 bugs
- Fixed: 15 bugs
- Pending: 5 bugs
- Fix rate: 50%

New Bugs

On recent version of OpenSSL

Pulse-X

- Total: 30 bugs
- Fixed: 15 bugs
- Pending: 5 bugs
- Fix rate: 50%

Pulse-X can find new bugs!

Summary

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Discrepancy as limitation

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- Theory: “Safe means Safe”

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- Practice: “Bug means Bug”

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Solution: Pulse-X

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Discrepancy as limitation

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- Incorrectness Separation Logic (ISL)

Summary

Discrepancy as limitation

- Theory: “Safe means Safe”
- Practice: “Bug means Bug”

Solution: Pulse-X

- Incorrectness Separation Logic (ISL)
    - Compositional analysis

Summary

Discrepancy as limitation

- Theory: “Safe means Safe”
- Practice: “Bug means Bug”

Solution: Pulse-X

- Incorrectness Separation Logic (ISL)
    - Compositional analysis
    - Under-approximated analysis

Summary

Discrepancy as limitation

- Theory: “Safe means Safe”
- Practice: “Bug means Bug”

Solution: Pulse-X

- Incorrectness Separation Logic (ISL)
  - Compositional analysis
  - Under-approximated analysis
- Better fix rate, Found new bugs