Synthesizing Benchmarks for Predictive Modeling

http://chriscummins.cc/cgo17

Fork me on GitHub

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THE UNIVERSITY of EDINBURGH informatics

EPSRC Centre for Doctoral Training in Pervasive Parallelism

EPSRC Engineering and Physical Sciences Research Council

machine learning for compilers

$$y = f(x)$$

Optimisations

CPU or GPU

Workgroup size

Cflags

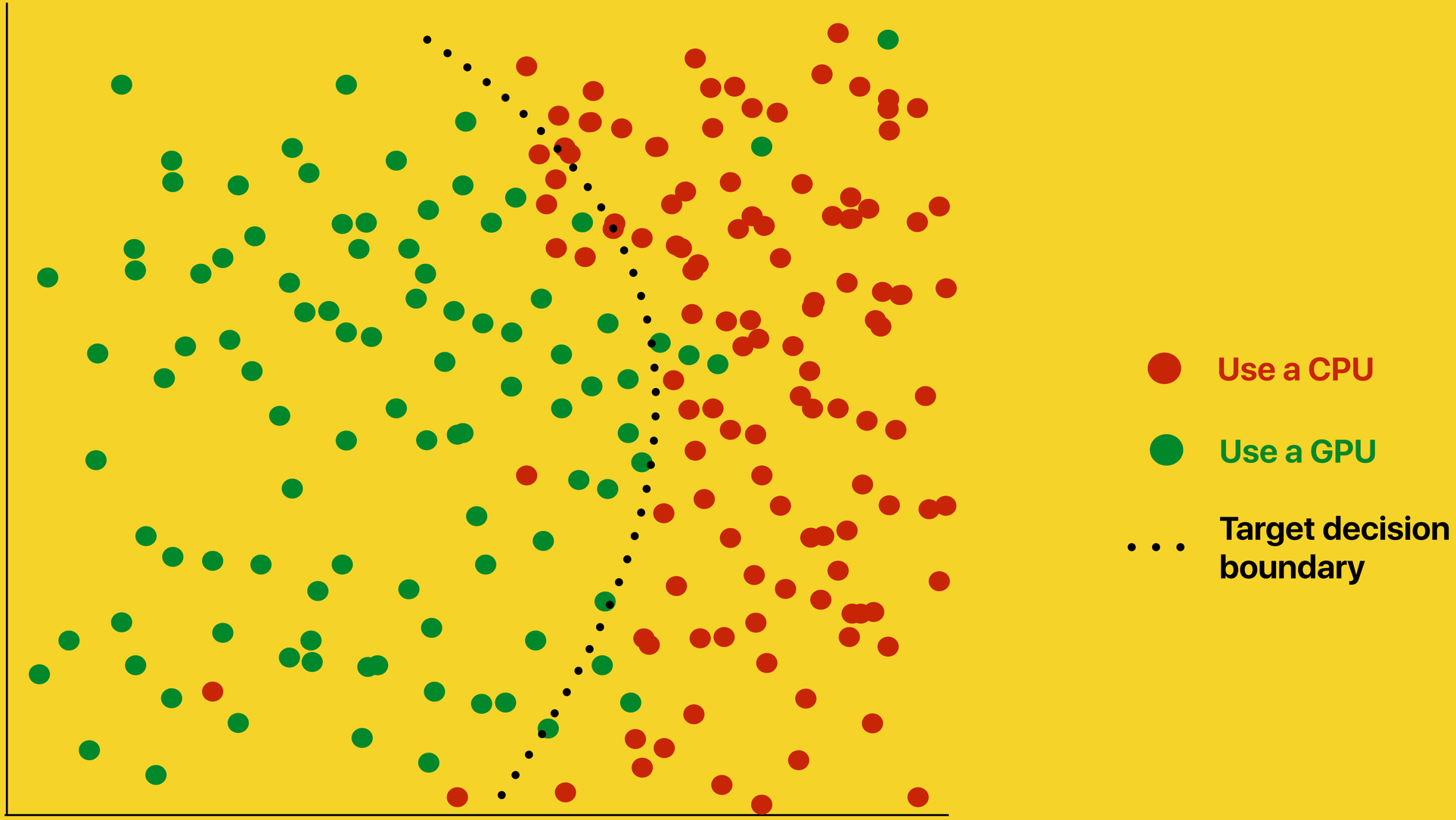
Features

instructions

Arithmetic density

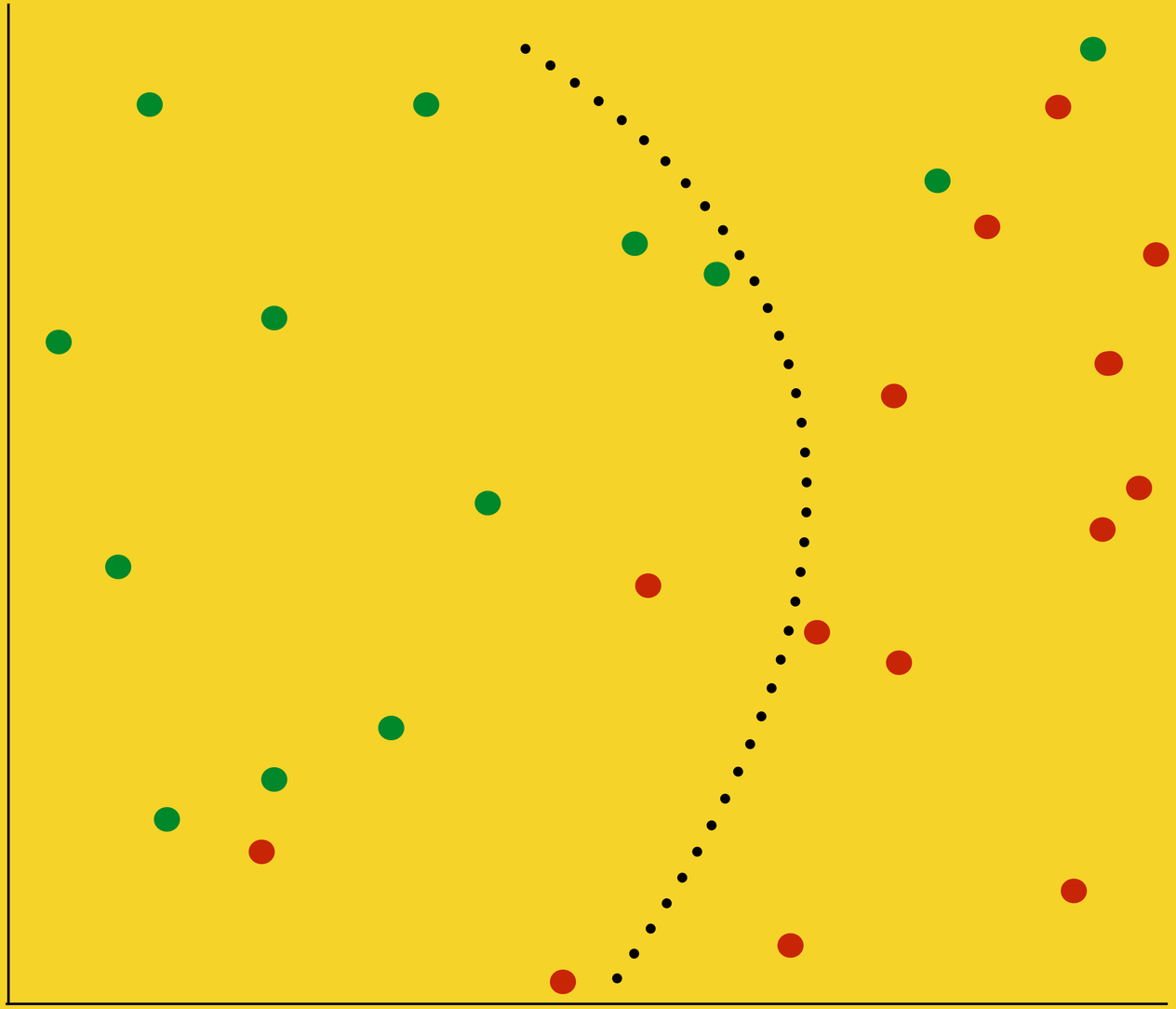
Dataset size

machine learning for compilers



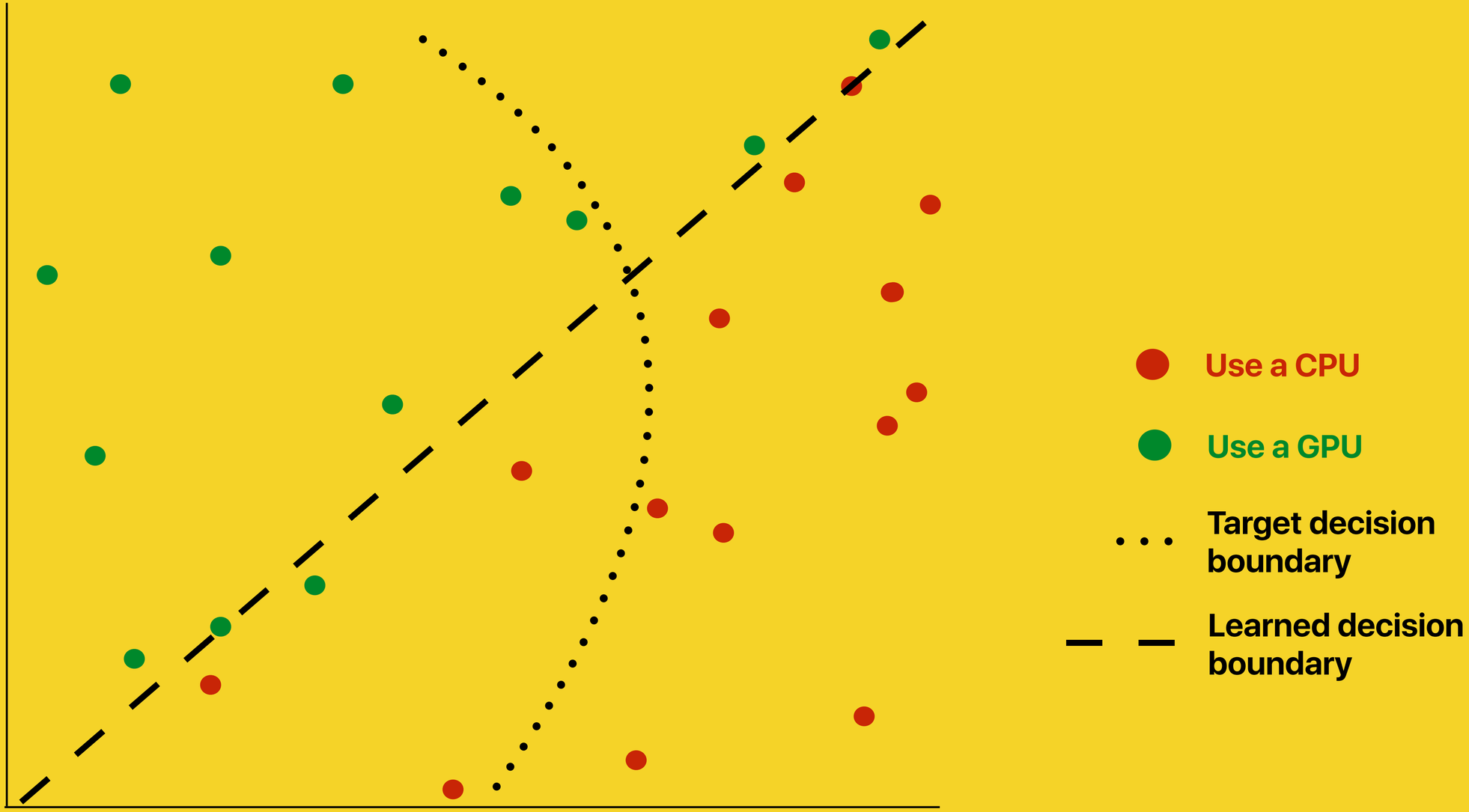
The idea.

machine learning for compilers



The reality.

machine learning for compilers



The reality.

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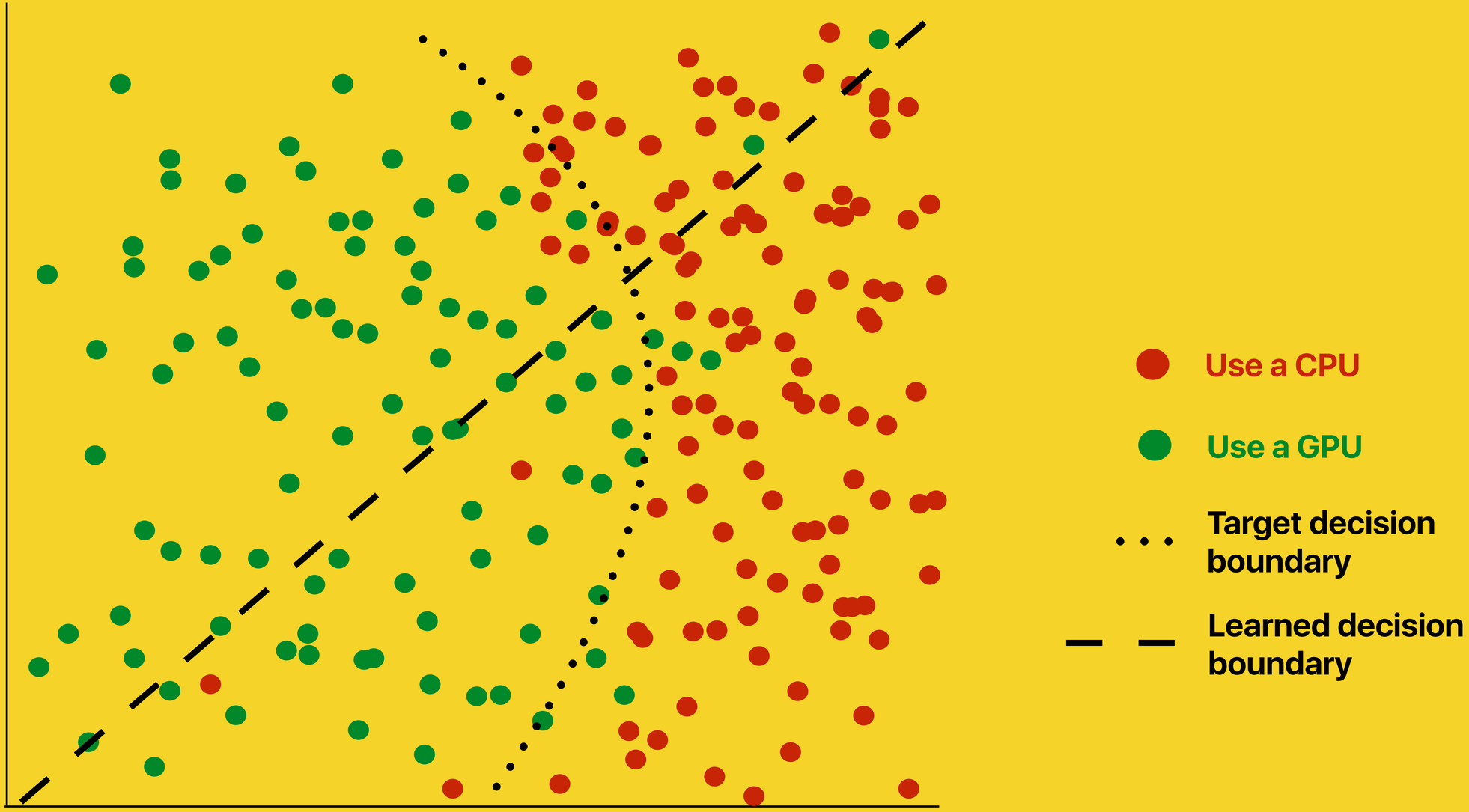
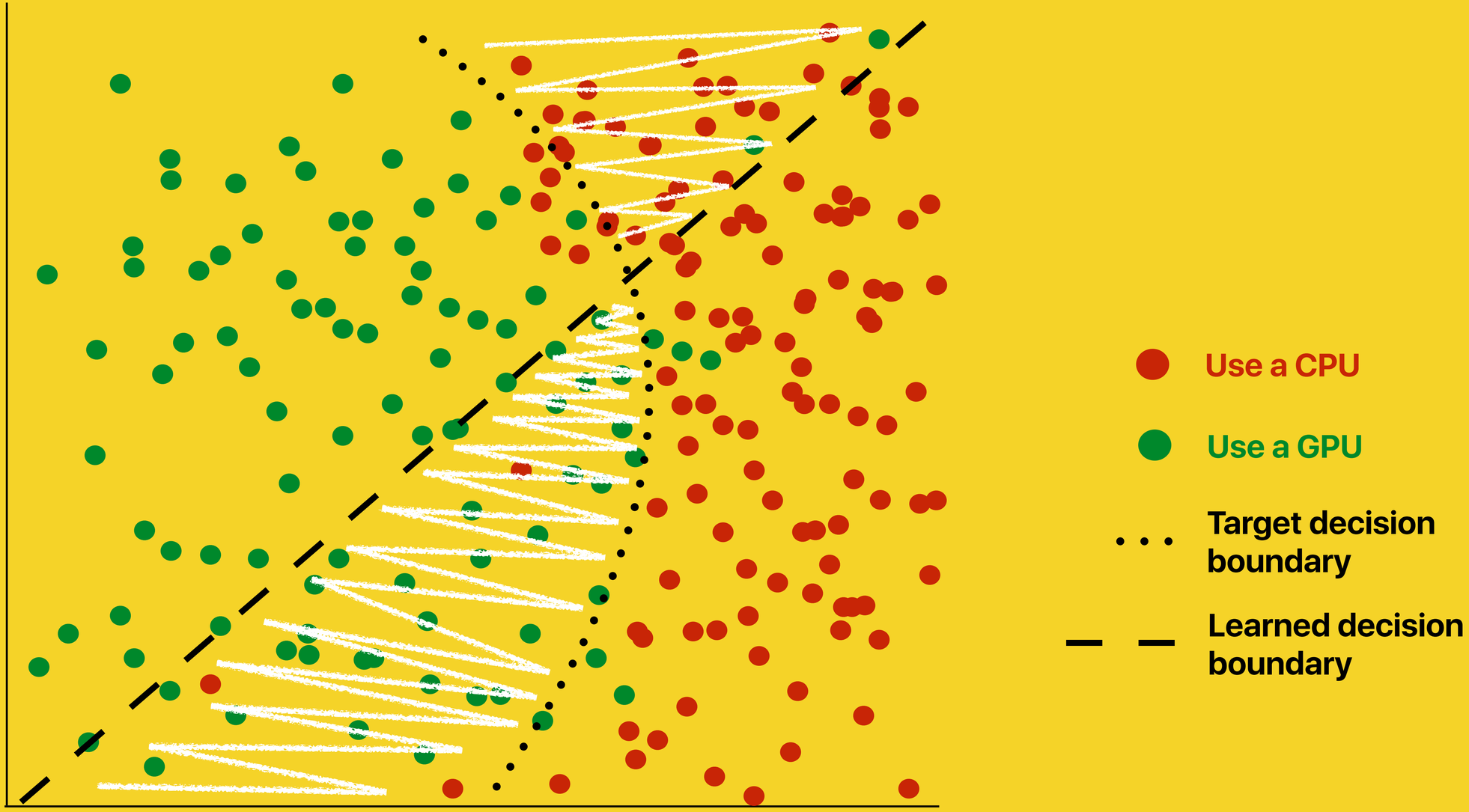


sparse data leads to inaccurate models!

machine learning for compilers



sparse data leads to inaccurate models!

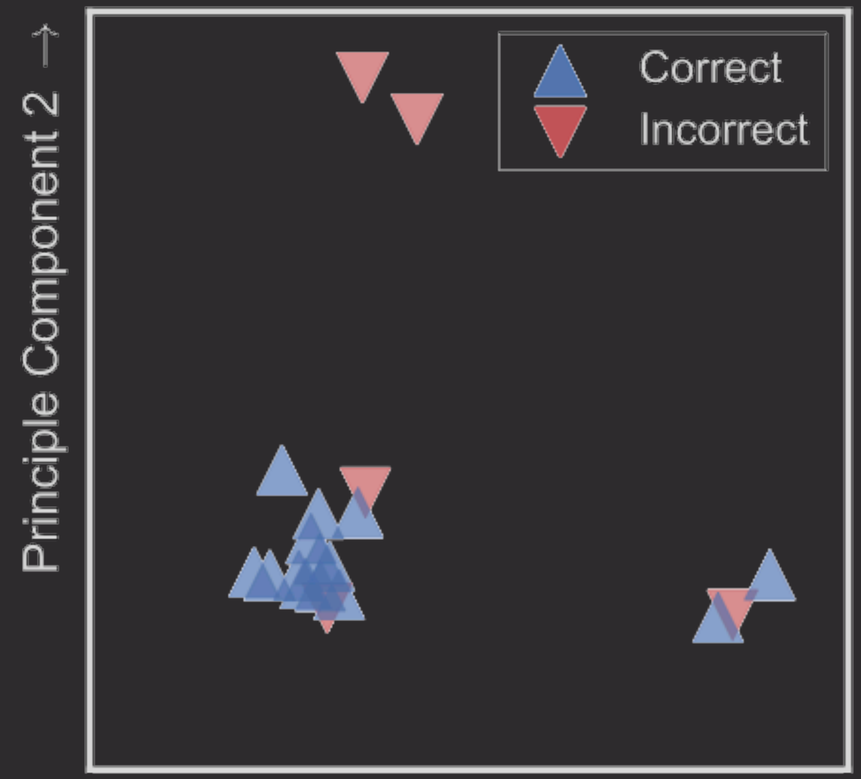
problem statement

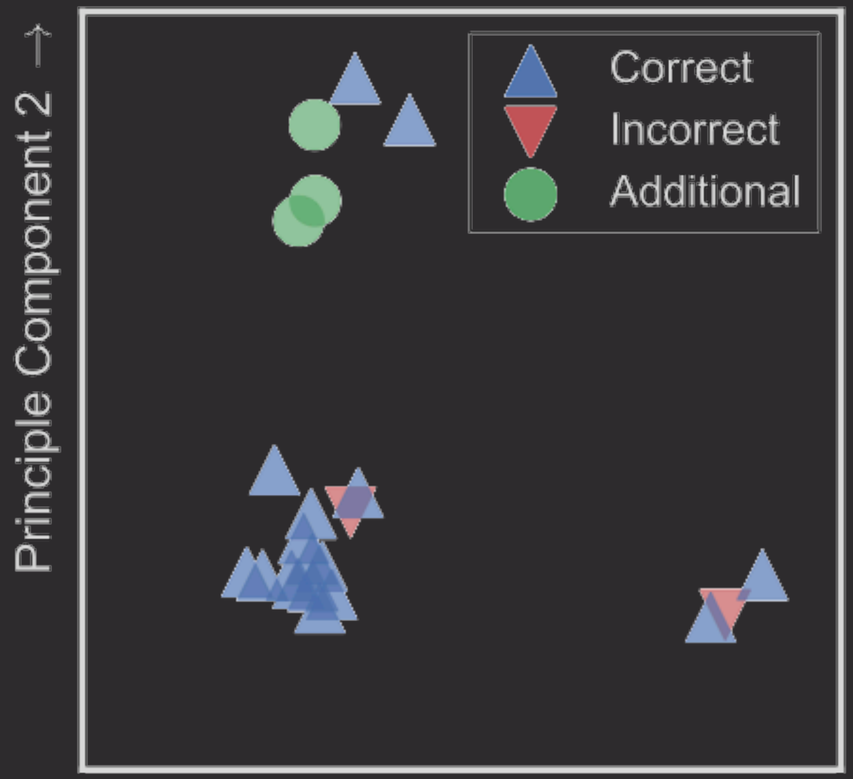
1. there aren't enough benchmarks

avg compiler paper	17	
Iris dataset	150	10×
MNIST dataset	60,000	10^3×
ImageNet dataset	10,000,000	10^6×

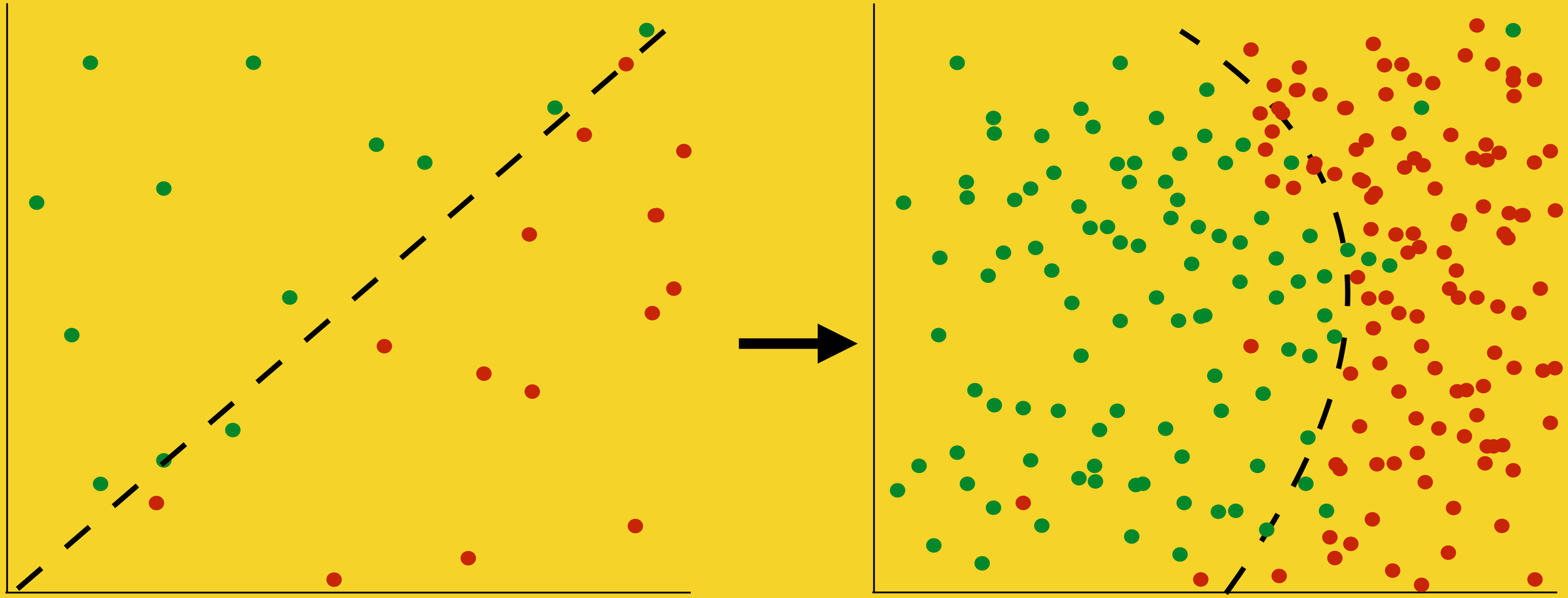
problem statement

1. there aren't enough benchmarks
2. more benchmarks = better models





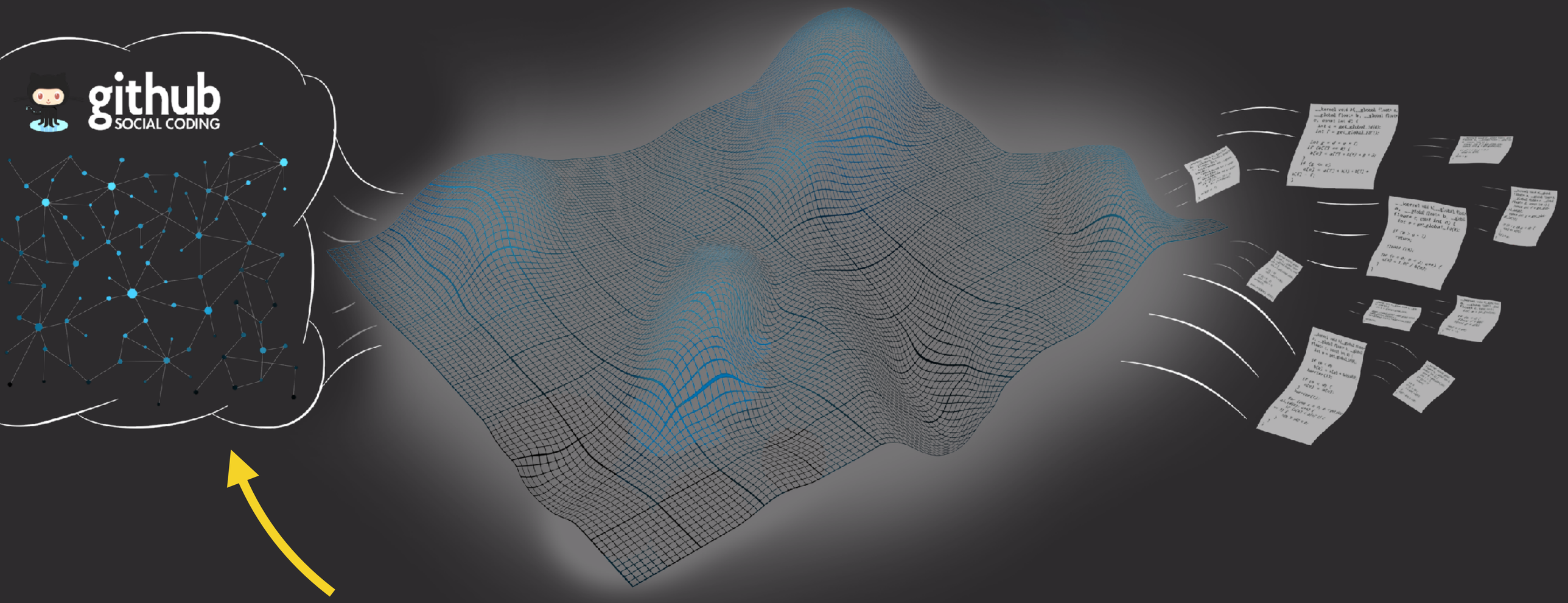
what we need



from this

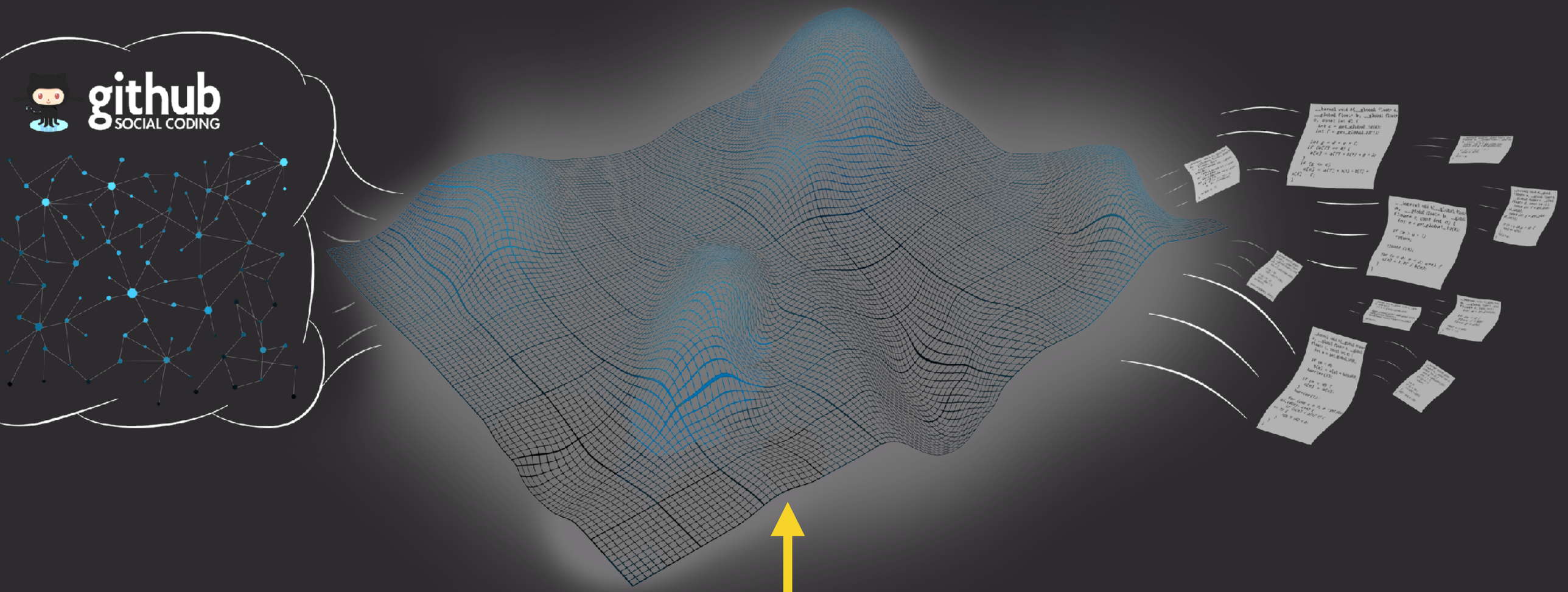
to this

our approach



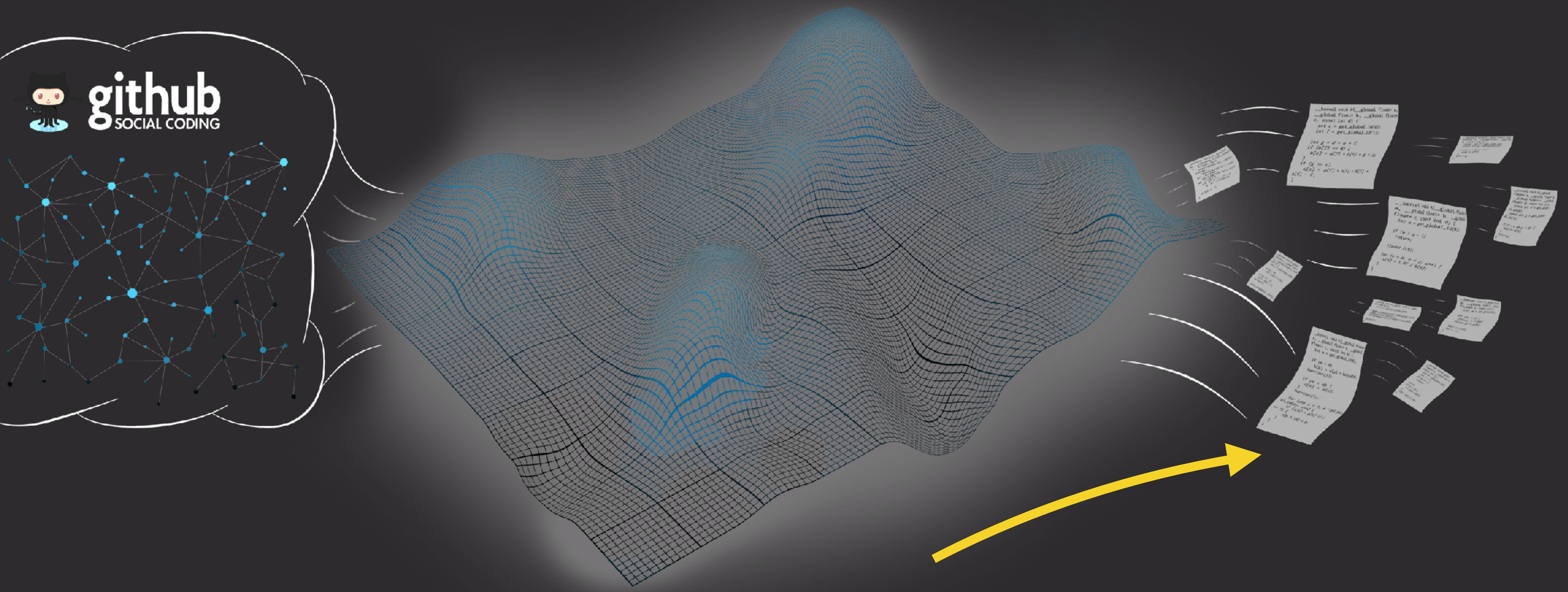
mine code from web

our approach



model source distr.

our approach



sample lang. model

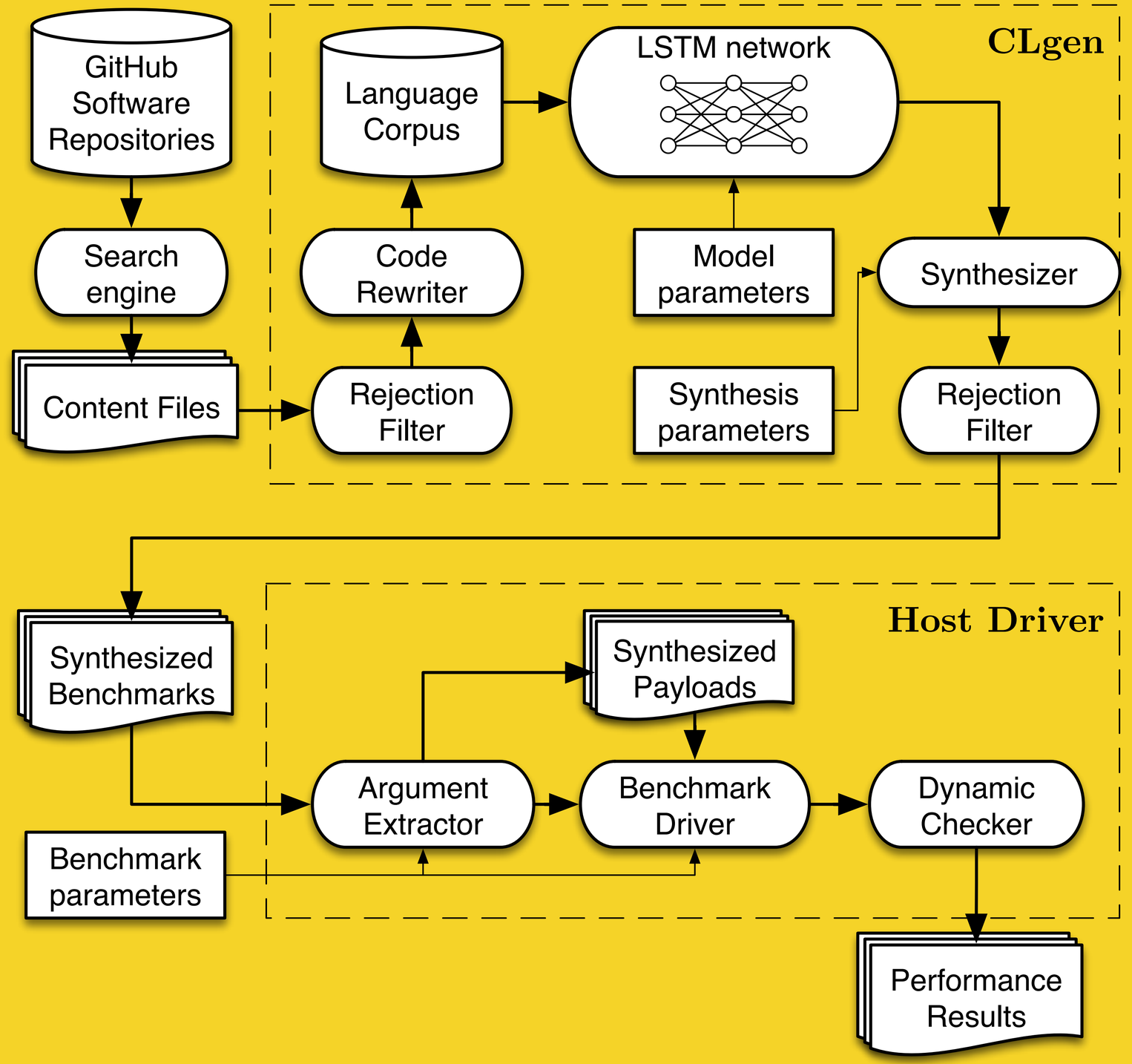
contributions

1. a deep learning approach to modeling PL semantics & usage

2. first solution for general purpose benchmark synthesis

3. automatic 1.27× speedup

4. improved model designs for further 4.30× speedup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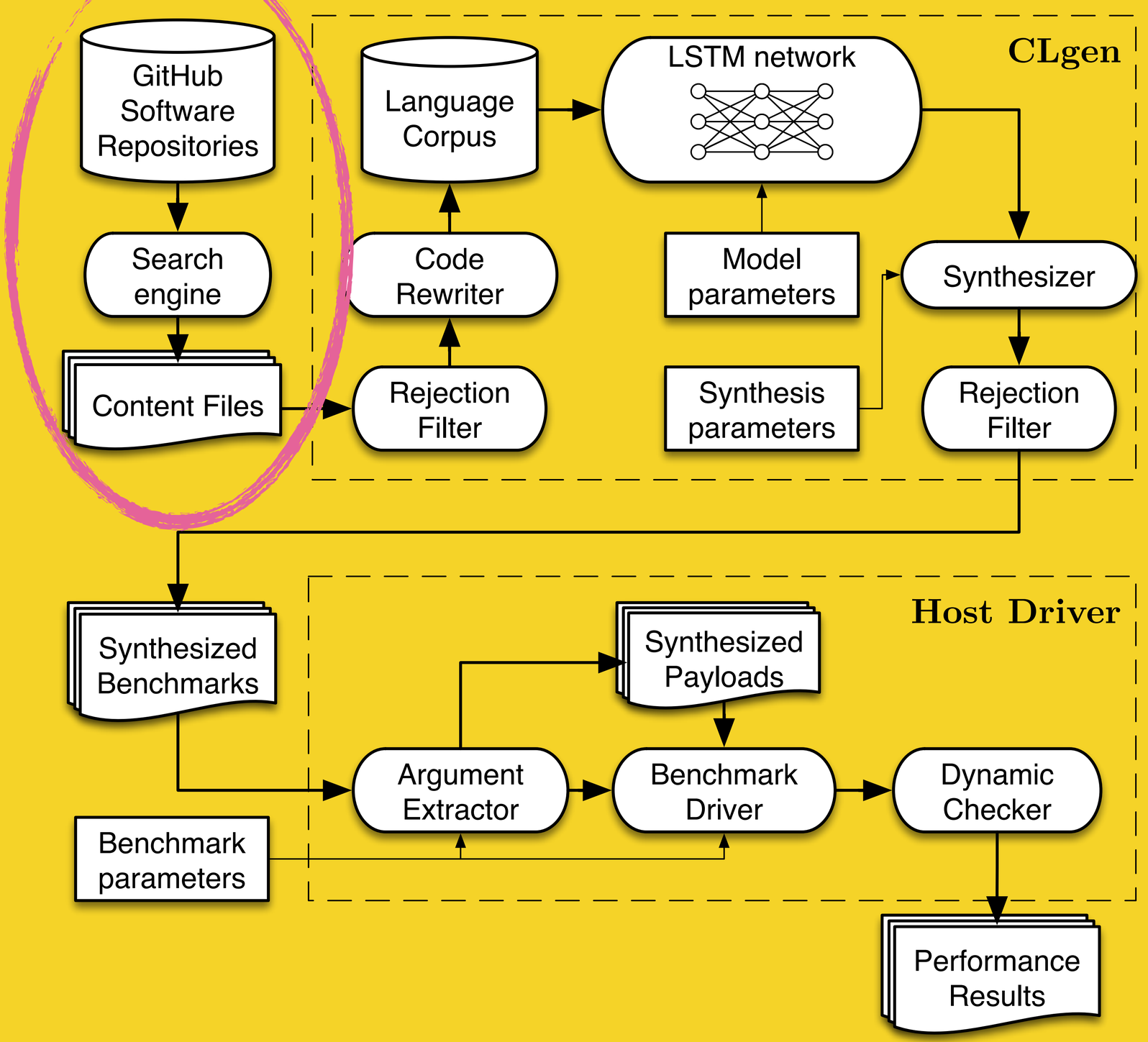
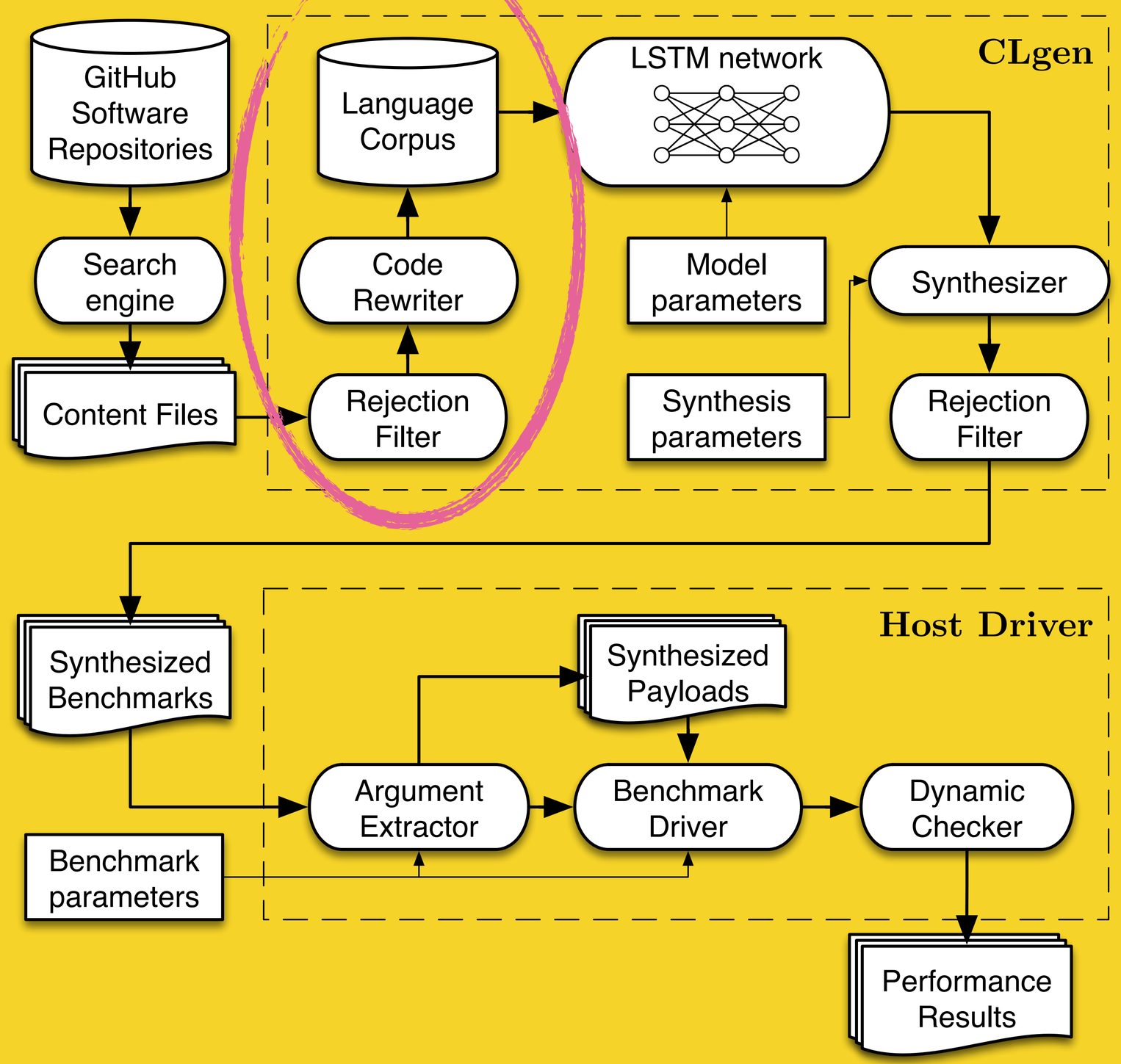
Dynamic Checker
Performance Results

8078 files

2.8M lines

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#define CLAMPING
#define THRESHOLD_MAX 1.0f

float myclamp(float in) {
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    return in > THRESHOLD_MAX ? THRESHOLD_MAX : in < 0.0f ? 0.0f : in;
#else
    return in;
#endif // CLAMPING
}

__kernel void findAllNodesMergedAabb(__global float* in, __global float* out,
                                     int num_elems)
{
   // Do something really flipping cool
   int id = get_global_id(0);
    if (id < num_elems)
    {


        out[id] = myclamp(in[id]);
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Is this real, valid OpenCL?
Can we minimise non-functional variance?

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Strip comments

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Skip comments

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~~Strip comments~~
Preprocess

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Does it compile?
Does it contain instructions?

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~~Does it contain instructions?~~

(33% discard rate)

~~Skip comments~~
~~Preprocess~~
Rewrite function names

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float A(float in) {
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__kernel void B(__global float* in, __global float* out,
                                    int num_elems)
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  int id = get_global_id(0);
    if (id < num_elems)
    {


        out[id] = A(in[id]);
    }
}
```

~~Strip comments~~

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Rewrite variable names

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__kernel void B(__global float* b, __global float* c,
                                   int d)
{
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    if (e < d)
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~~Strip comments~~

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Enforce code style

~~Does it compile?~~

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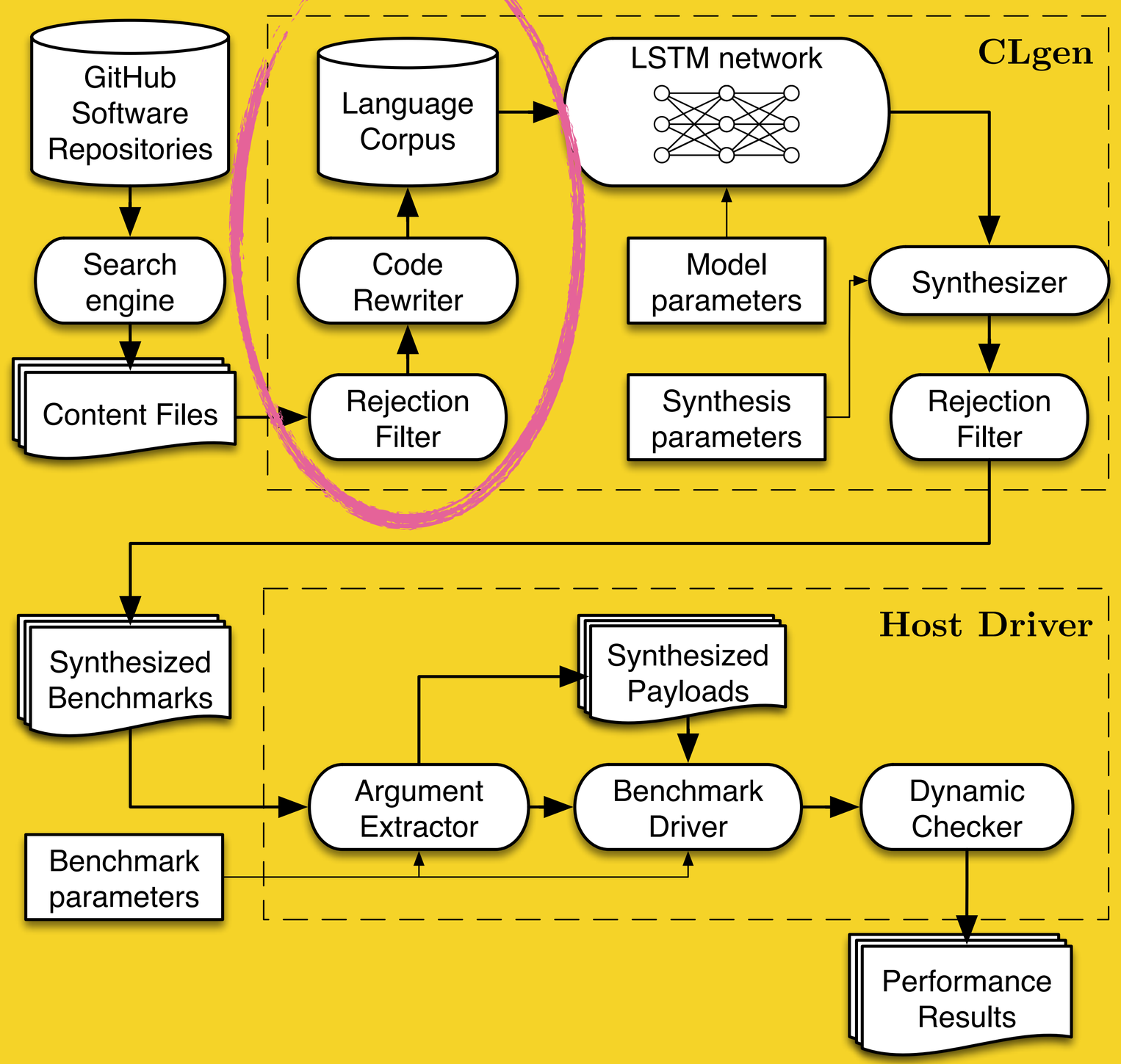
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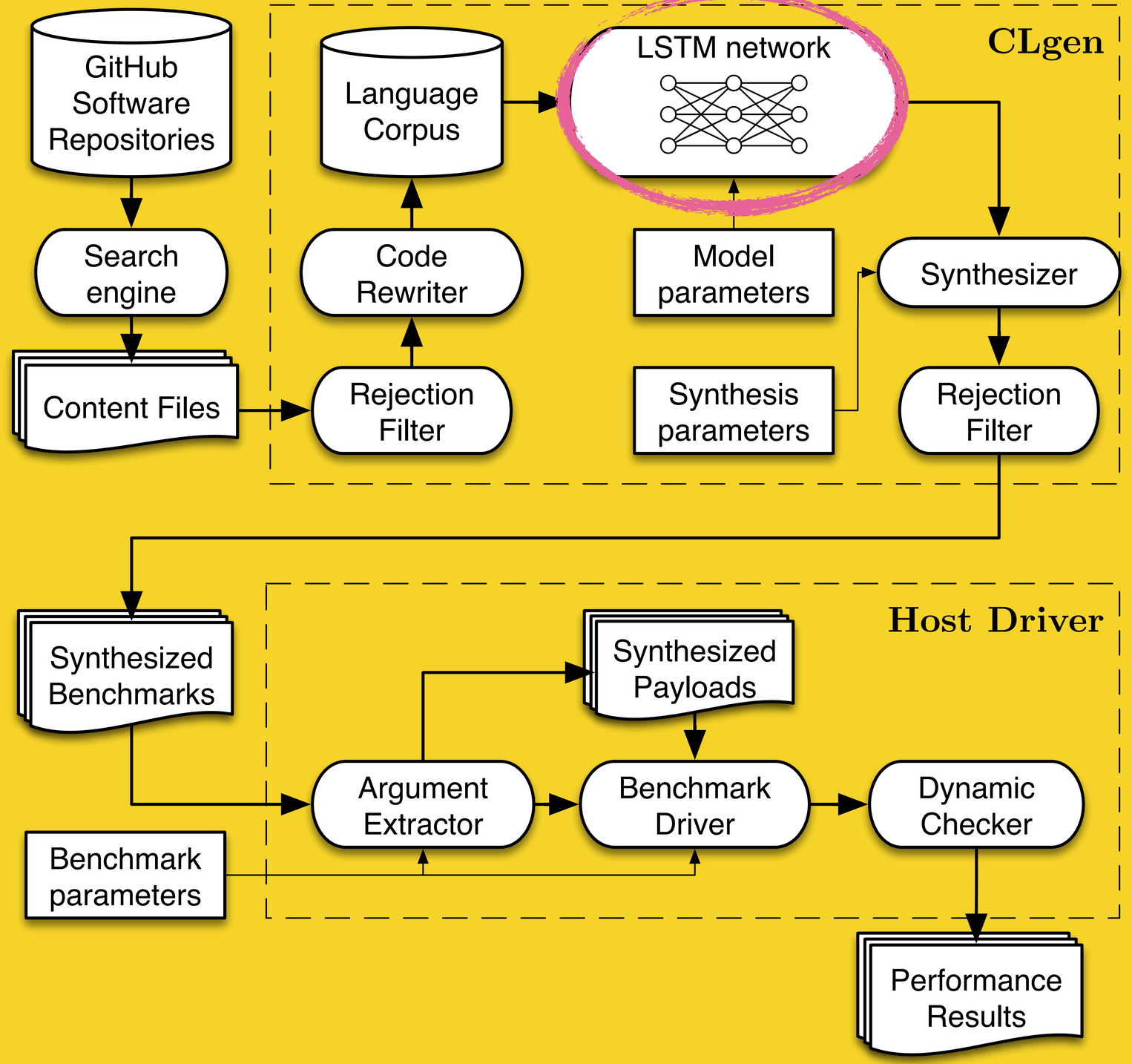
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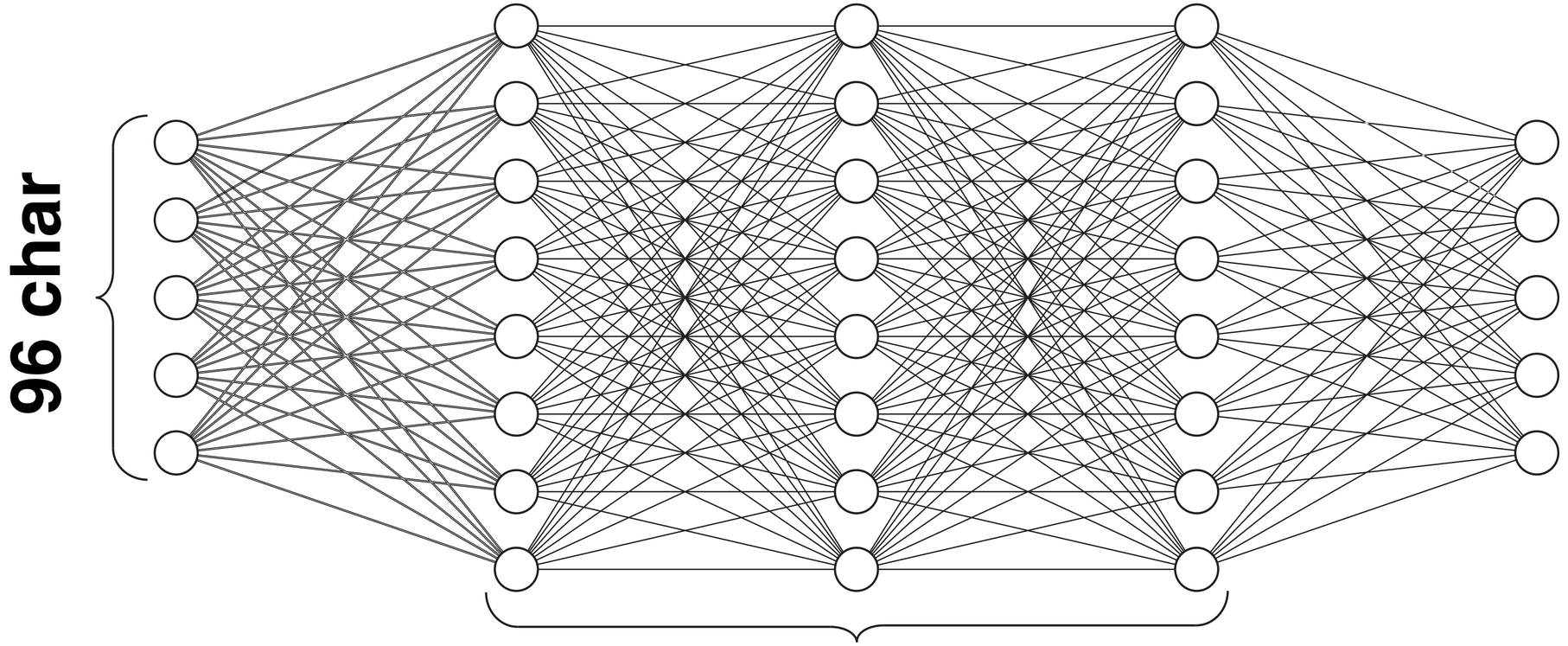
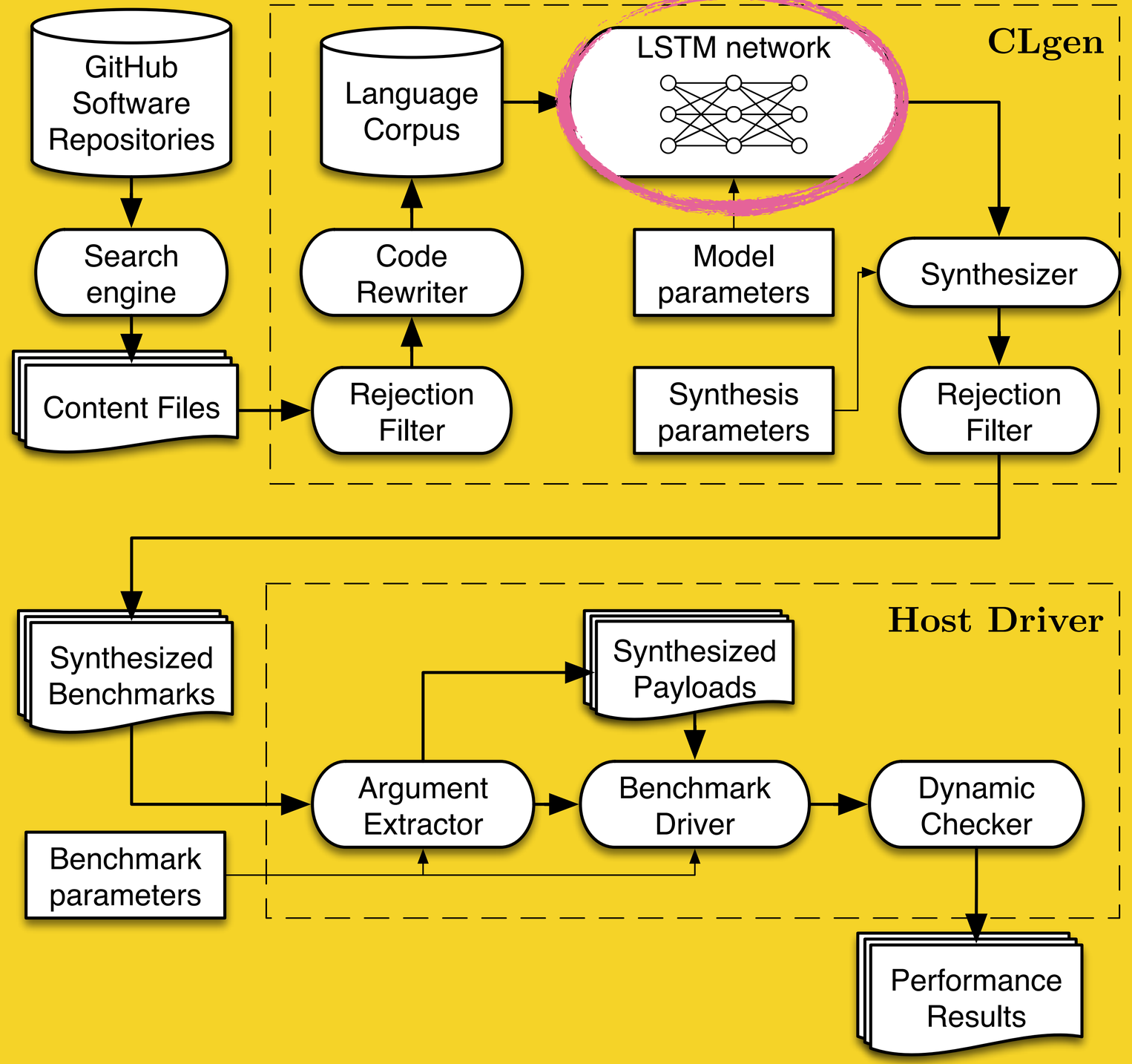


character level language model

$$y = f(x)$$

next char

char array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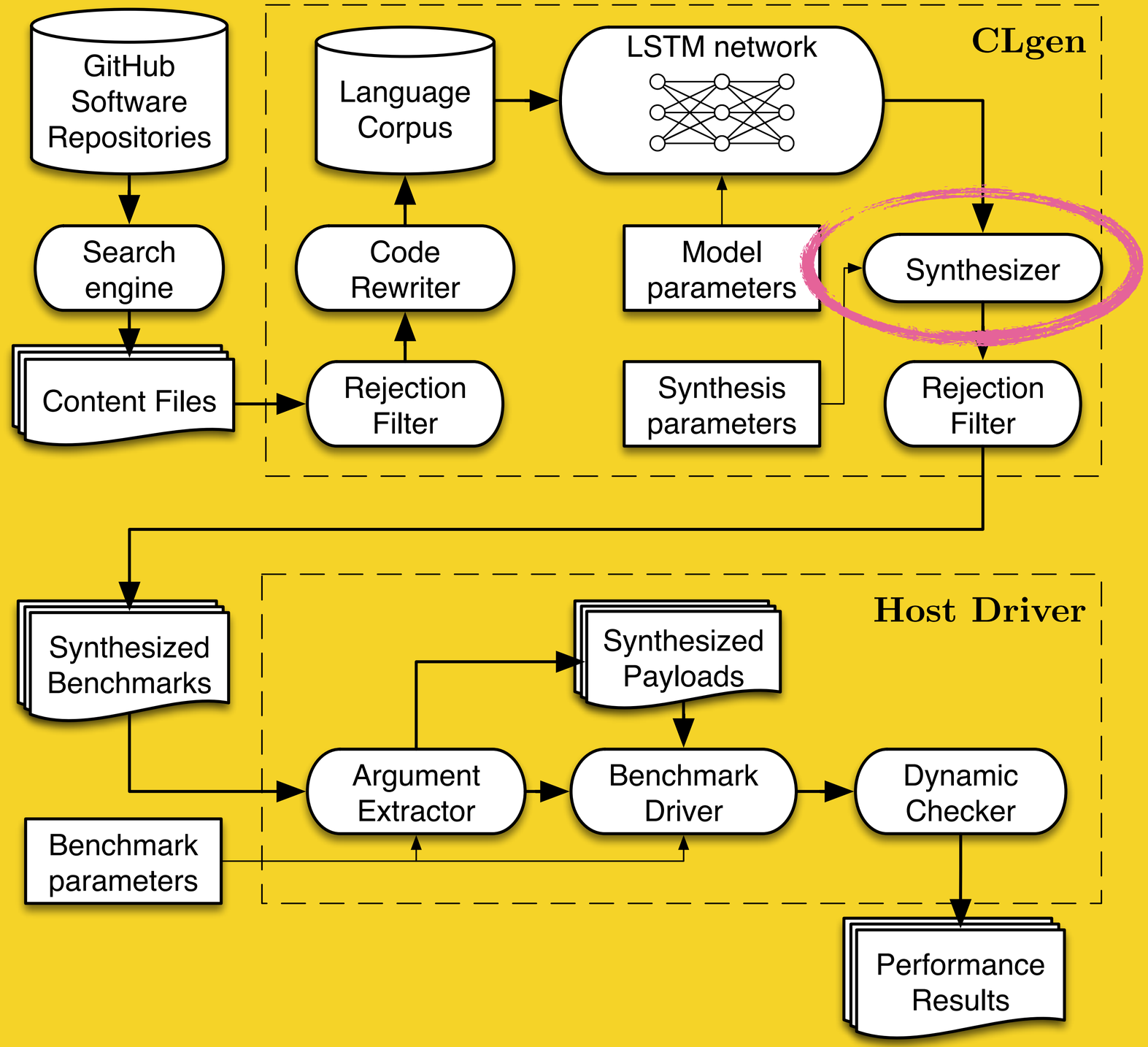
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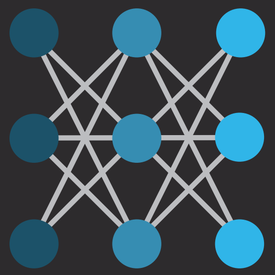
kernel synthesis

```
string S = ‘__kernel void A(__global float* a) {’
int depth = 1
while depth > 0:
   char c = predict_next_character(S)
   if c == ‘{’:
      depth += 1
   if c == ‘}’:
      depth -= 1
   S += c

return S
```



CLgen

Deep Learning Program Generator.


```
$ clgen model.json sampler.json
```

```
{
  “corpus": {
    “path": “~/kernels”
  },
  "model_type": "lstm",
  "rnn_size":   2048,
  "num_layers": 3,
  "max_epochs": 50
}
```

```
{
  "kernels": {
    "args": [
      "__global float*",
      "__global float*",
      "const int"
    ]
  },
  "sampler": {
    "max_kernels": 1000
  }
}
```

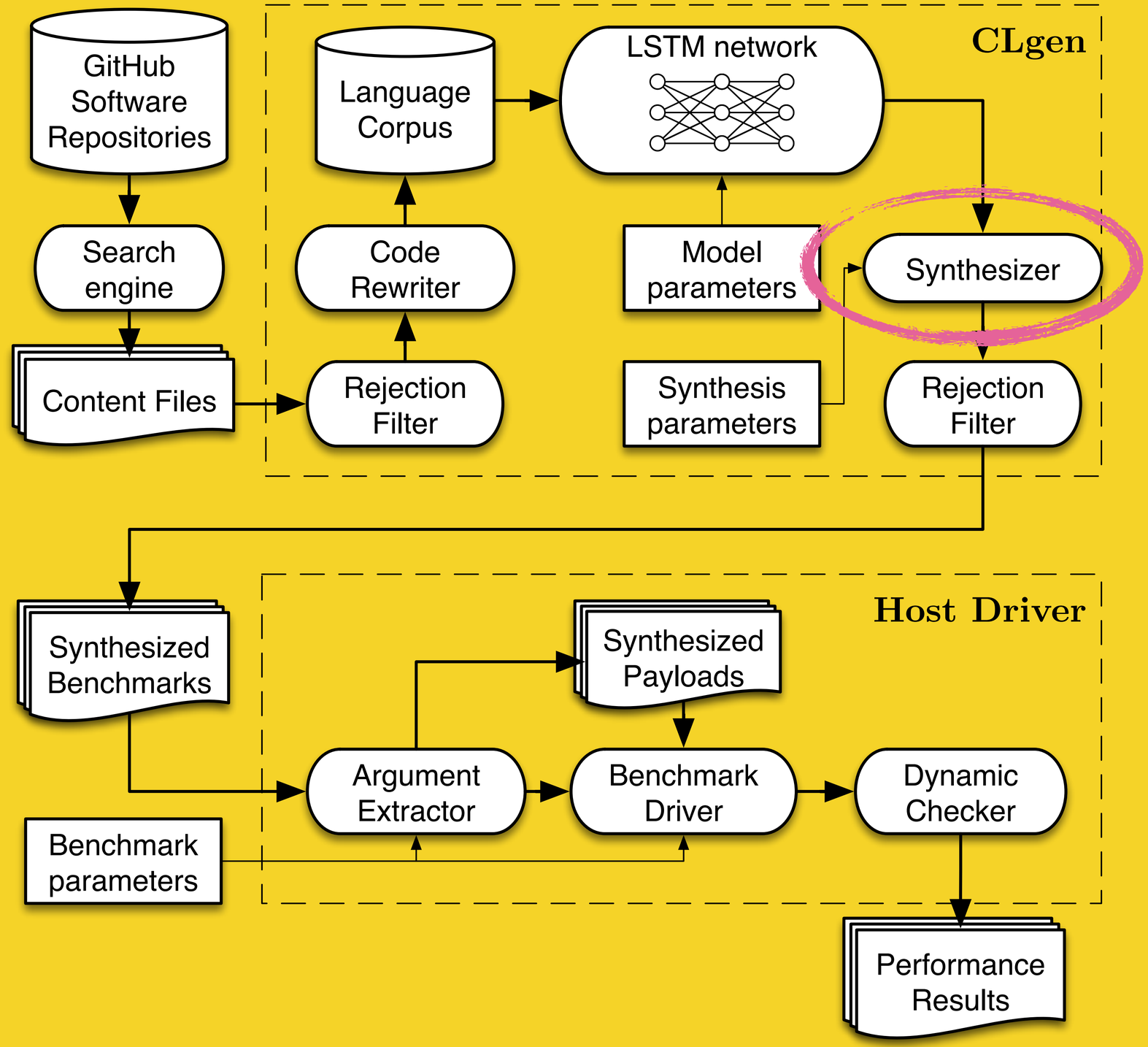
```
$ clgen model.json sampler.json 2>/dev/null
```

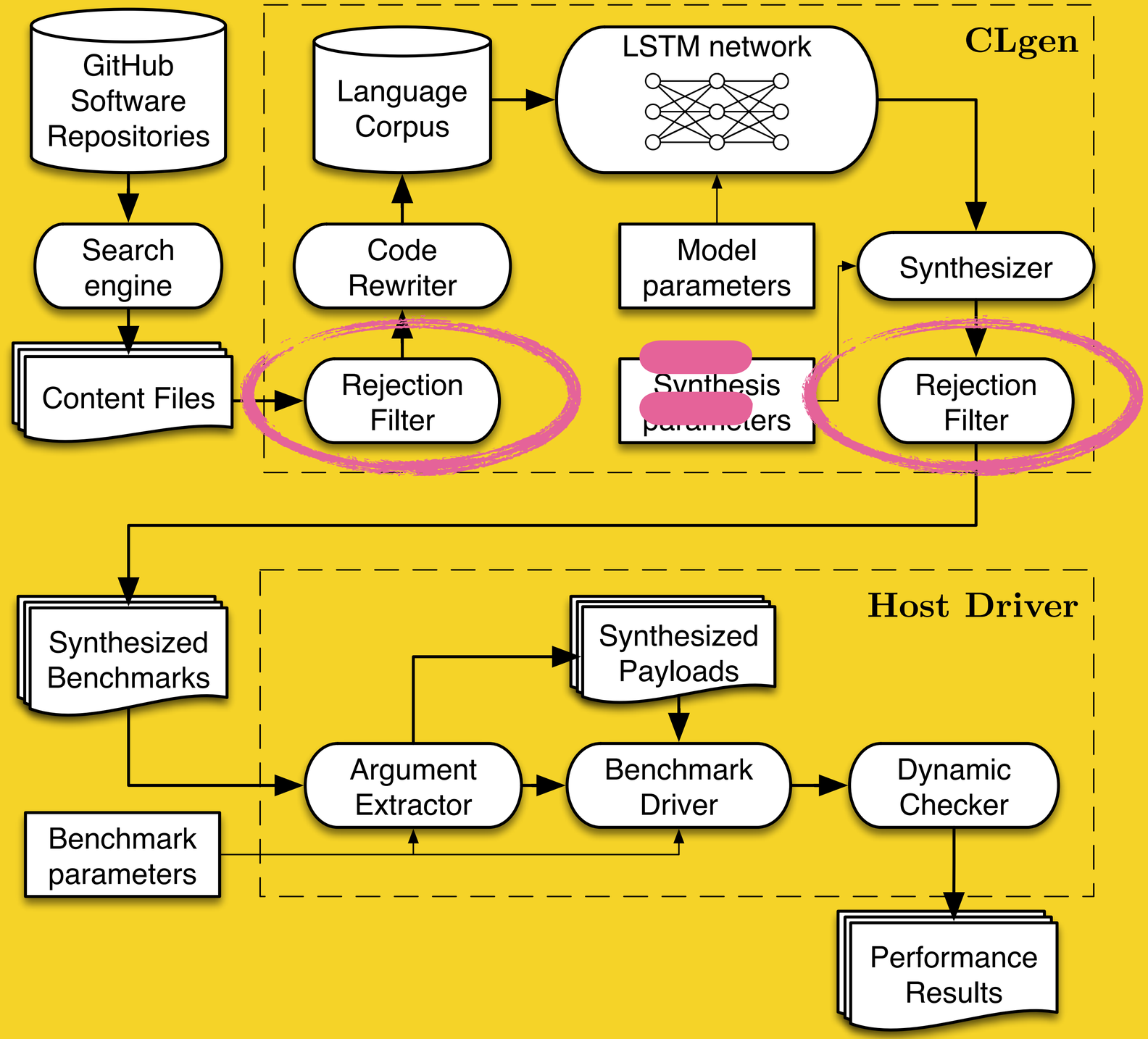
```
__kernel void A(__global float* a,
                __global float* b,
                __global float* c,
                const int d) {
  int e = get_global_id(0);
  float f = 0.0;
  for (int g = 0; g < d; g++) {
    c[g] = 0.0f;
  }
  barrier(1);

  a[get_global_id(0)] = 2 * b[get_global_id(0)];
}
```

```
__kernel void A(__global float* a,
                __global float* b,
                __global float* c,
                const int d) {
  int e = get_global_id(0);
  if (e >= d) {
    return;
  }
  c[e] = a[e] + b[e] + 2 * a[e] + b[e] + 4;
}
```

```
__kernel void A(__global float* a,
                __global float* b,
                __global float* c,
                const int d) {
  unsigned int e = get_global_id(0);
  float16 f = (float16)(0.0);
  for (unsigned int g = 0; g < d; g++) {
    float16 h = a[g];
    f.s0 += h.s0;
    f.s1 += h.s1;
    /* snip ... */
    f.sE += h.sE;
    f.sF += h.sF;
  }
  b[e] = f.s0 + f.s1 + f.s2 + f.s3 + f.s4 +
     f.s5 + f.s6 + f.s7 + f.s8 + f.s9 + f.sA +
     f.sB + f.sC + f.sD + f.sE + f.sF;
}
```


CLgen
GitHub Software Repositories
Search engine
Content Files
Rejection Filter
Language Corpus
Code Rewriter
LSTM network
Model parameters
Synthesis parameters
Synthesizer
Rejection Filter
Host Driver
Synthesized Benchmarks
Benchmark parameters
Argument Extractor
Synthesized Payloads
Benchmark Driver
Dynamic Checker
Performance Results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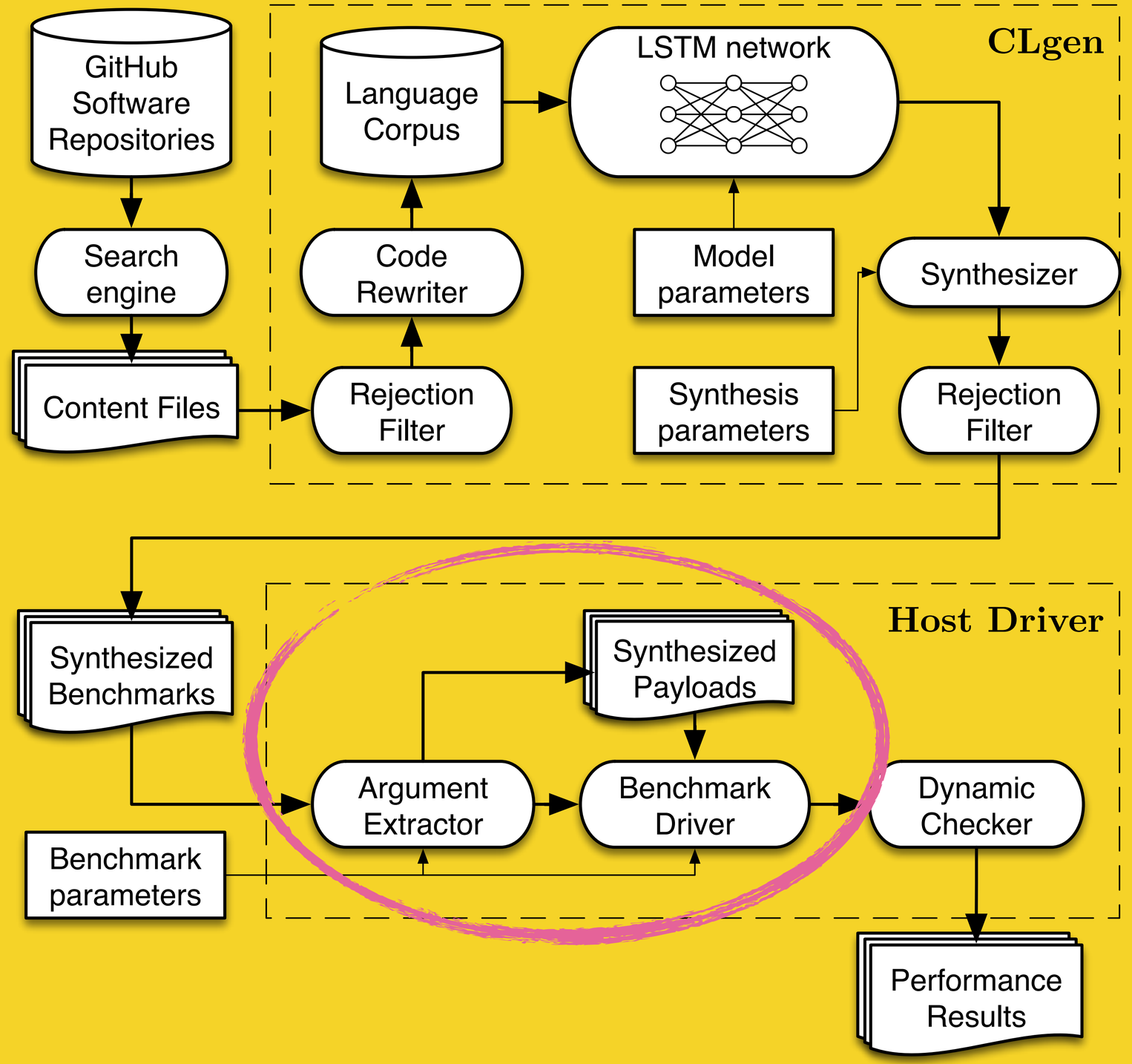
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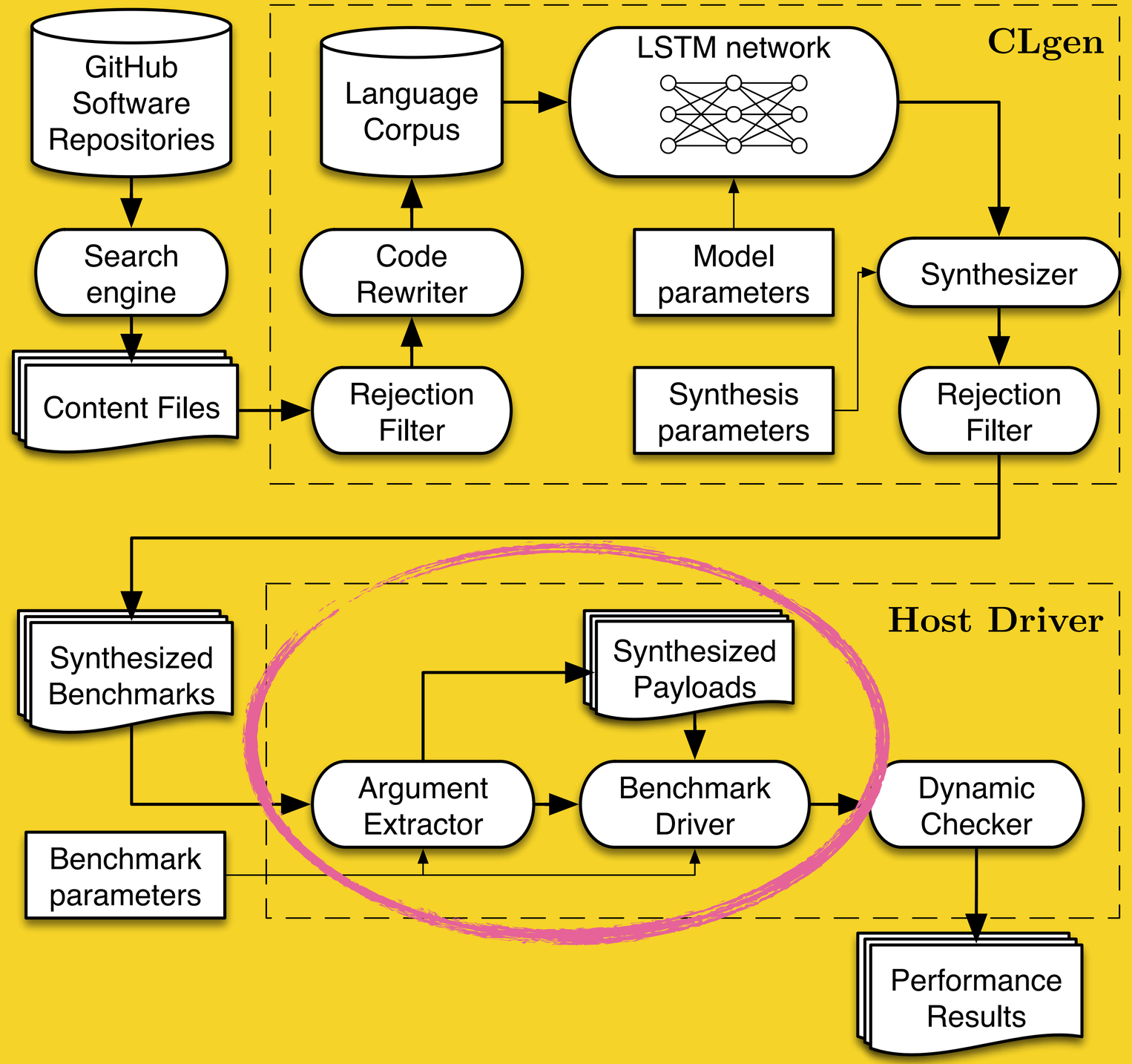
Benchmark Driver
Dynamic Checker
Performance Results

```
__kernel void A(__global float* a,
                __global float* b,
                __global float* c,
                const float d,
                const int e) {
  int f = get_global_id(0);
  if (f >= e) {
    return;
  }
  c[f] = a[f] + b[f] + 2 * c[f] + d + 4;
}
```

Payload for size S: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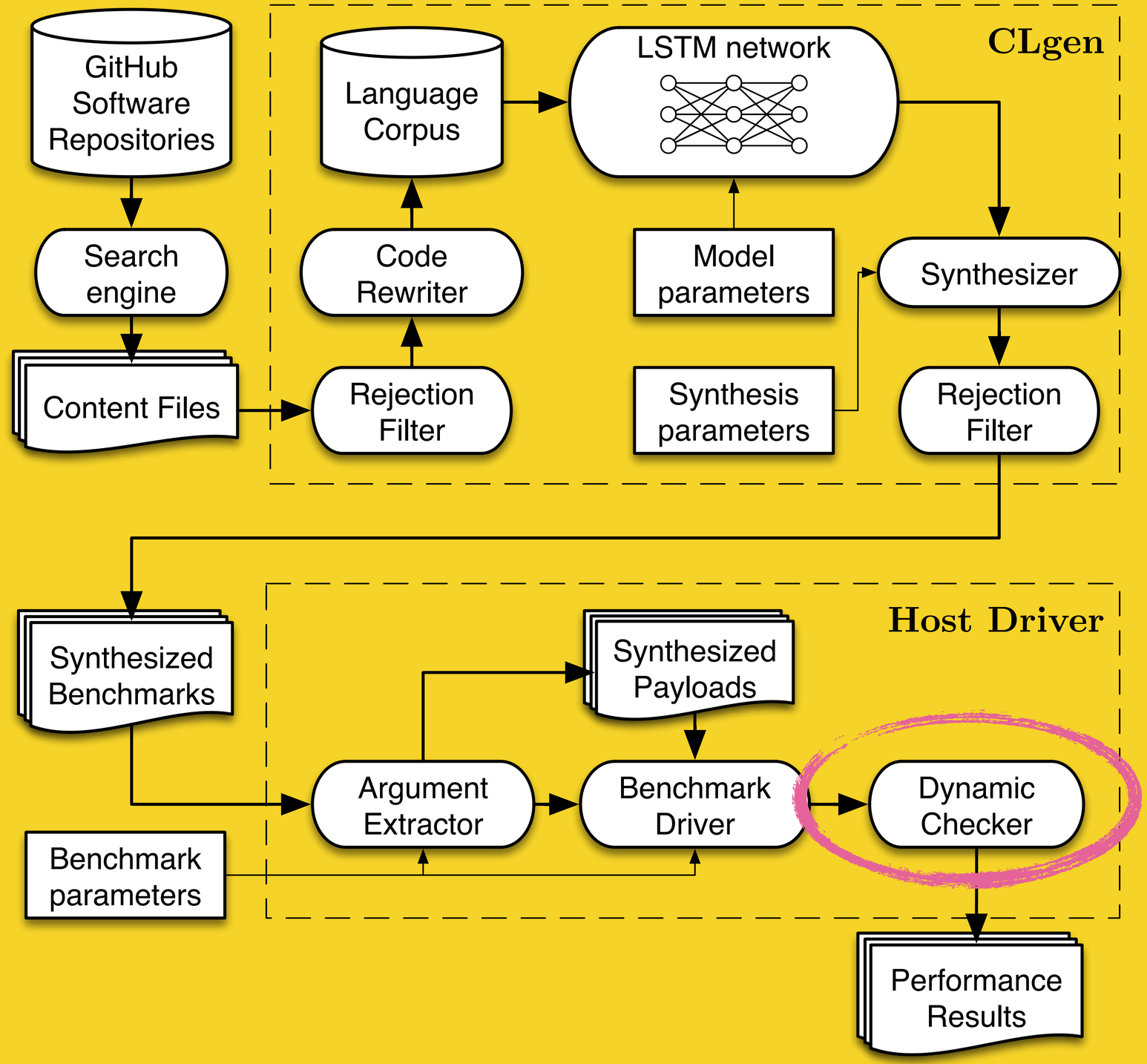
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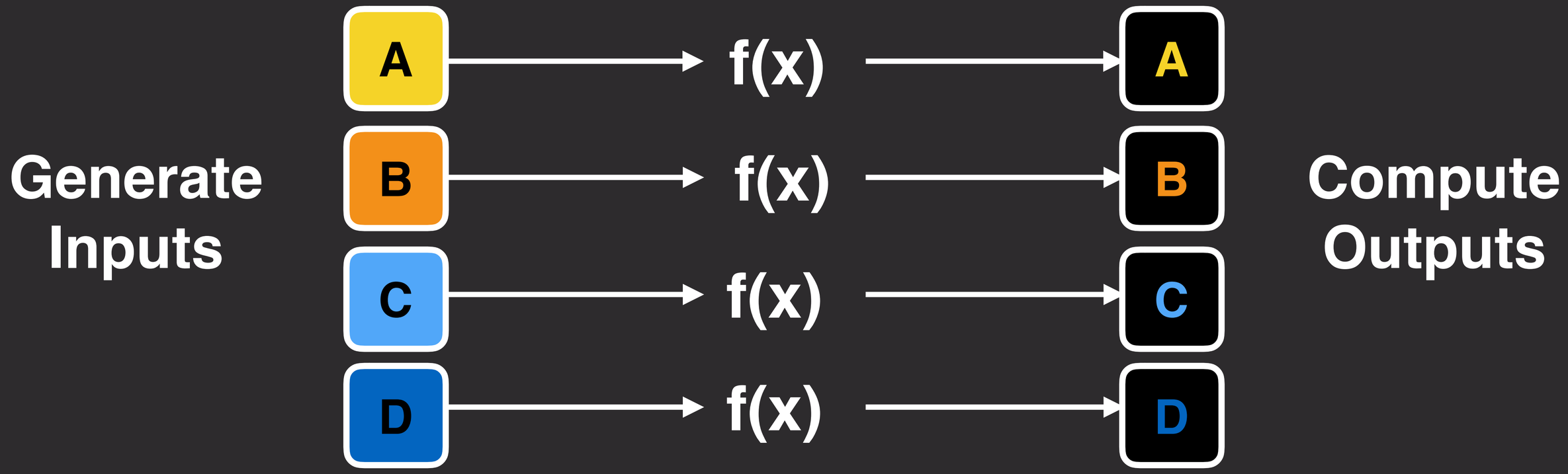
Performance Results

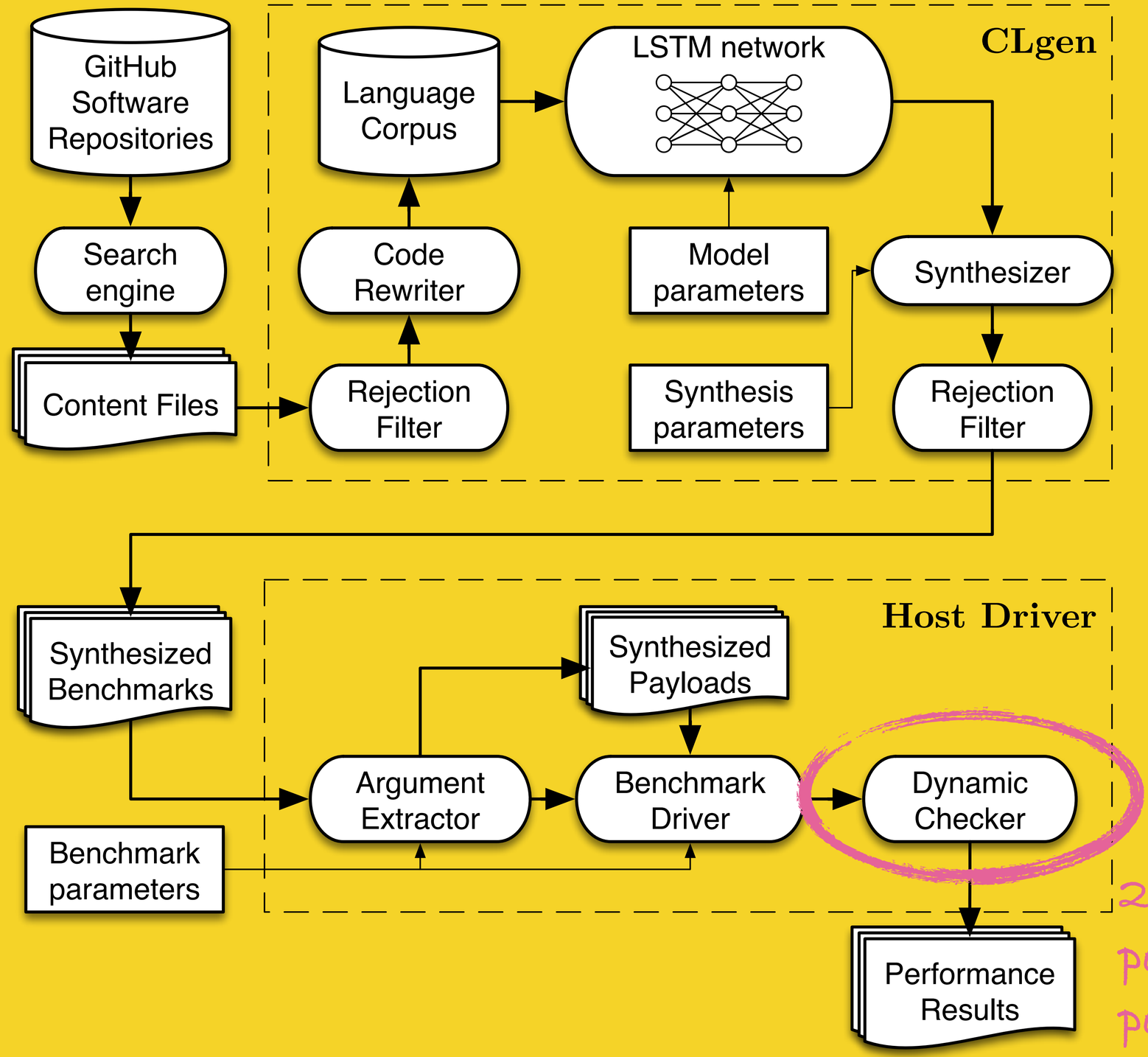


Verify:

A ≠ A else *no outputs*

A ≠ C else *input insensitive*

A = B else *non deterministic*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Dynamic Checker
Performance Results
2000 benchmarks per machine per day

results

Listing 3: Sample 3

```
__kernel void A(__global int* a, __global int* b, __global int* c,
    ↪ __global int* d, const uint e) {
  const uint f = get_global_id(0);

  if (e == 0 && f == 0)
    *d = 0;
  else if (f < e) {
    int g = b[f];
    uint h = c[f];
    if (g > 0) {
      a[h] = f;
      h++;
    }
    if (f == e - 1)
      *d = h;
  }
}
```

Listing 4: Sample 4

```
__kernel void A(__global float* a, __global float* b, __global float* c,
    ↪ const int d) {
  int e = get_global_id(0);

  if (e < d) {
    float f = b[e];
    float g = a[e];
    a[e] = f * 3.141592f / (f + 1.0f + e * 1024 - f) - (0.5f * g * 1.0f
        ↪ / 18.0f + e / 2.0f);
  }

  for (c = 0; c < 30; c++) {
    c[e] = 0;
  }
}
```

Listing 4: Sample 4

```
__kernel void A(int a, __global float* b, __global int* c, __global int*
    ↪ d, __local int* e, int f) {
  int g = get_local_id(0);
  e[get_local_id(0)] = 0;
  barrier(1);
  while (g < f) {
    int h = c[g];

    if (h != -1) {
      __global float* i = b + g * a;
      float j = 0;
```

Listing 7: Sample 7

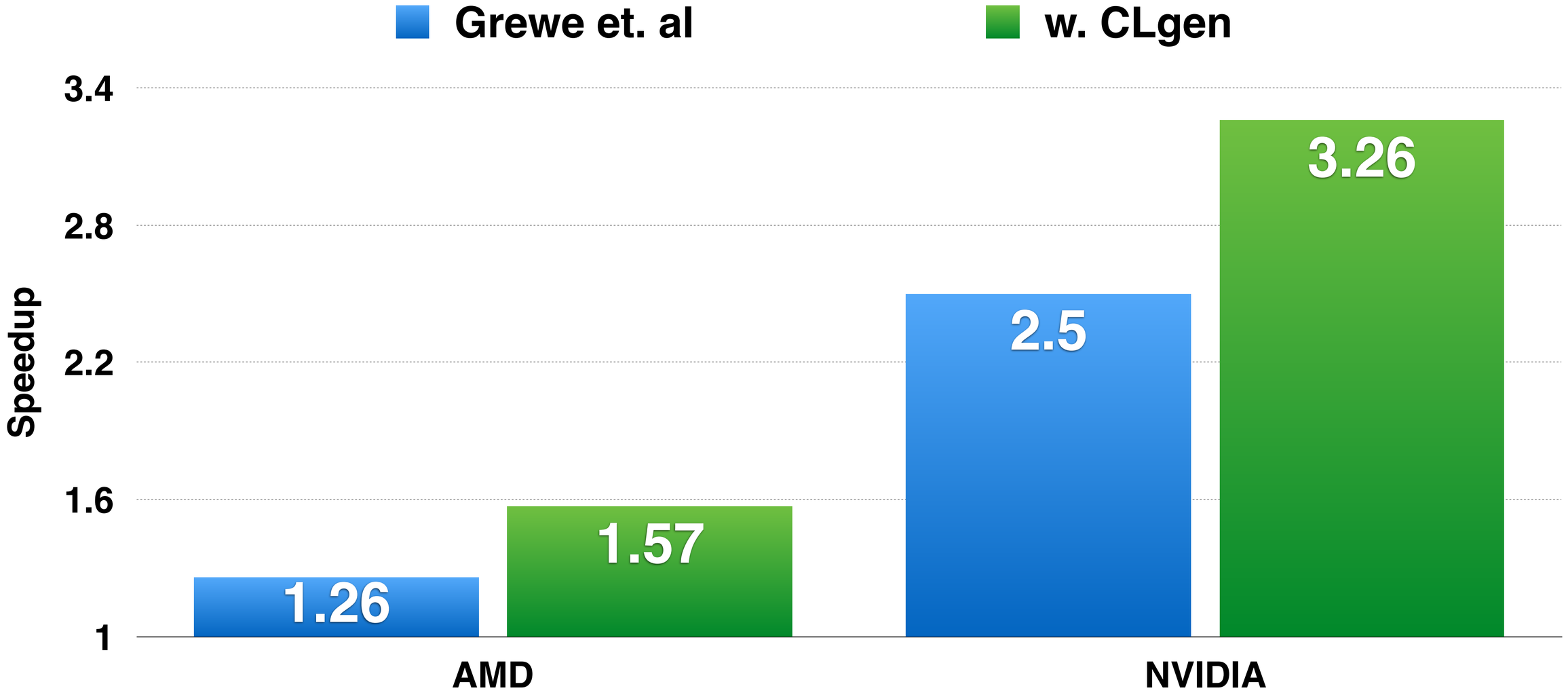
```
__kernel void A(int a, int b, int c, __global const float* d, __global
    ↪ const float* e, __global float* f, float g) {
  const int h = get_local_id(0);
  const int i = get_group_id(0);

  const int j = 4 * i + h;
  const int k = 4 * i + h + a;
  if (4 * i + h + a < c) {
    float l = 0.0;
    float m = 0.0;
    float n = 0.0;
    const float o = d[3 * (4 * i + h + a)];
    const float p = d[3 * (4 * i + h + a) + 1];
    const float q = d[3 * (4 * i + h + a) + 2];
    for (int r = 0; r < c; r++) {
      const float s = d[3 * r] - o;
      const float t = d[3 * r + 1] - p;
      const float u = d[3 * r + 2] - q;
      const float v = (d[3 * r] - o) * (d[3 * r] - o) + (d[3 * r + 1] -
          ↪ p) * (d[3 * r + 1] - p) + (d[3 * r + 2] - q) * (d[3 * r +
          ↪ 2] - q) + g;
      const float w = e[r] / (((d[3 * r] - o) * (d[3 * r] - o) + (d[3 *
          ↪ r + 1] - p) * (d[3 * r + 1] - p) + (d[3 * r + 2] - q) * (d
          ↪ [3 * r + 2] - q) + g) * sqrt((d[3 * r] - o) * (d[3 * r] - o
          ↪ ) + (d[3 * r + 1] - p) * (d[3 * r + 1] - p) + (d[3 * r + 2]
          ↪ ] - q) * (d[3 * r + 2] - q) + g));
      l = l + (d[3 * r] - o) * w;
      m = m + (d[3 * r + 1] - p) * w;
      n = n + (d[3 * r + 2] - q) * w;
    }
    f[3 * (4 * i + h)] = l;
    f[3 * (4 * i + h) + 1] = m;
    f[3 * (4 * i + h) + 2] = n;
  }
}
```

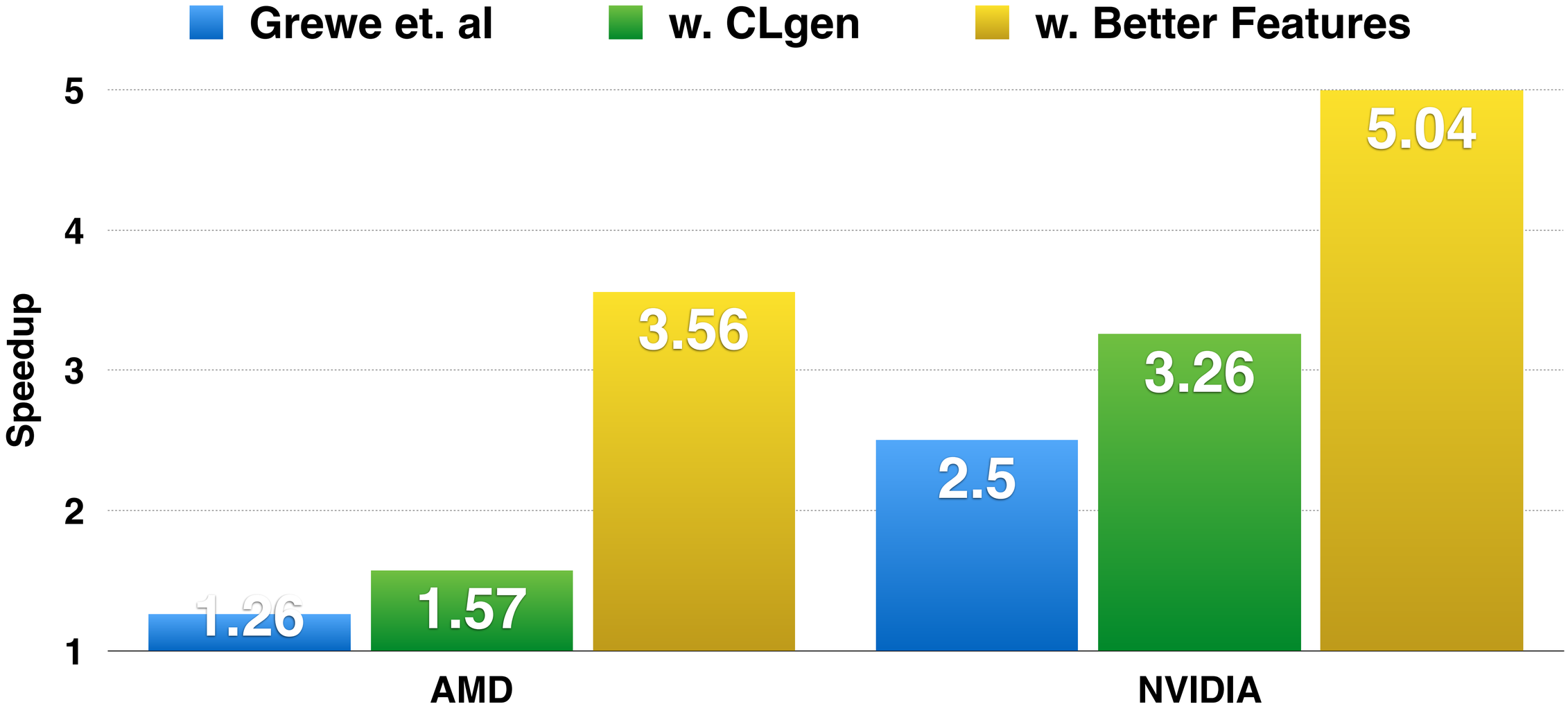

Listing 10: Sample 10

```
__kernel void A(__global ulong *a) {
    int i, j;
    struct S0 c_8;
    struct S0* p_7 = &c_8;
    struct S0 c_9 = {
        {{0x43250E6DL,2UL},{0x43250E6DL,2UL},{0x43250E6DL,2UL},
         {0x43250E6DL,2UL},{0x43250E6DL,2UL},{0x43250E6DL,2UL},
         {0x43250E6DL,2UL},{0x43250E6DL,2UL}},
        0x4BF90EDCAD2086BDL,
    };
    c_8 = c_9;
    barrier(0 | 1);
```

7 benchmarks, 1,000 synthetic benchmarks. 1.27x faster



71 benchmarks, 1,000 synthetic benchmarks. 4.30x faster



concluding remarks

problem: insufficient benchmarks

use DL to learn PL semantics and usage

turing tested! ;-)

improved model performance and design

Synthesizing Benchmarks for Predictive Modeling

For the paper, code and data:

http://chriscummins.cc/cgo17

For the TensorFlow neural network:

http://chriscummins.cc/clgen

Extra slides

1. Synthesis algorithm
2. Predictive model features
3. Experimental Setup
4. Model Hyperparameters
5. Limitations & Strengths

Algorithm 1 Sampling a candidate kernel from a seed text.

Require: LSTM model M, maximum kernel length n.
Ensure: Completed sample string S.

$S \leftarrow$ "`__kernel void A(const int a) {`" *Seed text*
$d \leftarrow 1$ *Initial code block depth*
for $i \leftarrow |S|$ **to** n **do**
    $c \leftarrow predictcharacter(M, S)$ *Generate new character*
    if $c =$ "`{`" **then**
        $d \leftarrow d + 1$ *Entered code block, increase depth*
    else if $c =$ "`}`" **then**
        $d \leftarrow d - 1$ *Exited code block, decrease depth*
    end if
    $S \leftarrow S + c$ *Append new character*
    if $depth = 0$ **then**
        break *Exited function block, stop sampling*
    end if
end for

Raw Code Features		
`comp`	static	#. compute operations
`mem`	static	#. accesses to global memory
`localmem`	static	#. accesses to local memory
`coalesced`	static	#. coalesced memory accesses
`transfer`	dynamic	size of data transfers
`wgsize`	dynamic	#. work-items per kernel

(a) Individual code features

Combined Code Features	
F1: `transfer/(comp+mem)`	commun.-computation ratio
F2: `coalesced/mem`	% coalesced memory accesses
F3: `(localmem/mem)` × `wgsize`	ratio local to global mem accesses × #. work-items
F4: `comp/mem`	computation-mem ratio

(b) Combinations of raw features

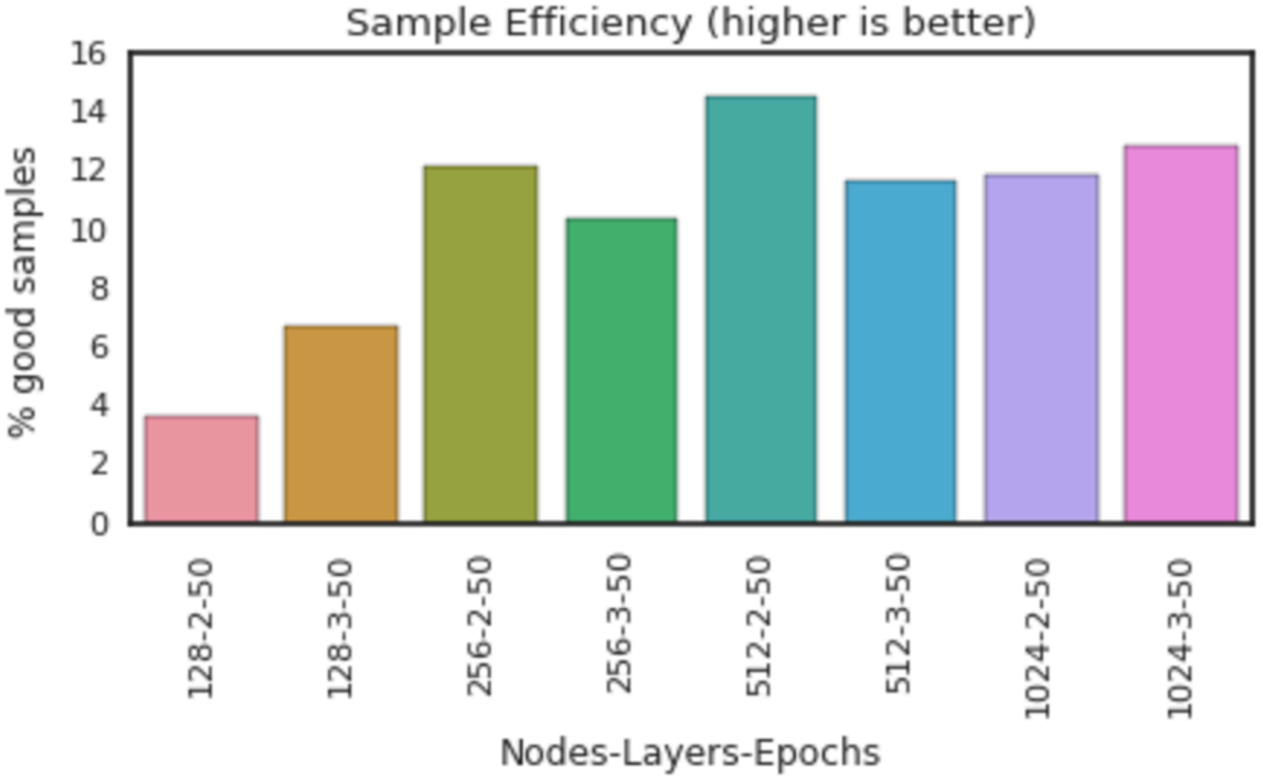
Table 2. *Grewe et al.* model features.

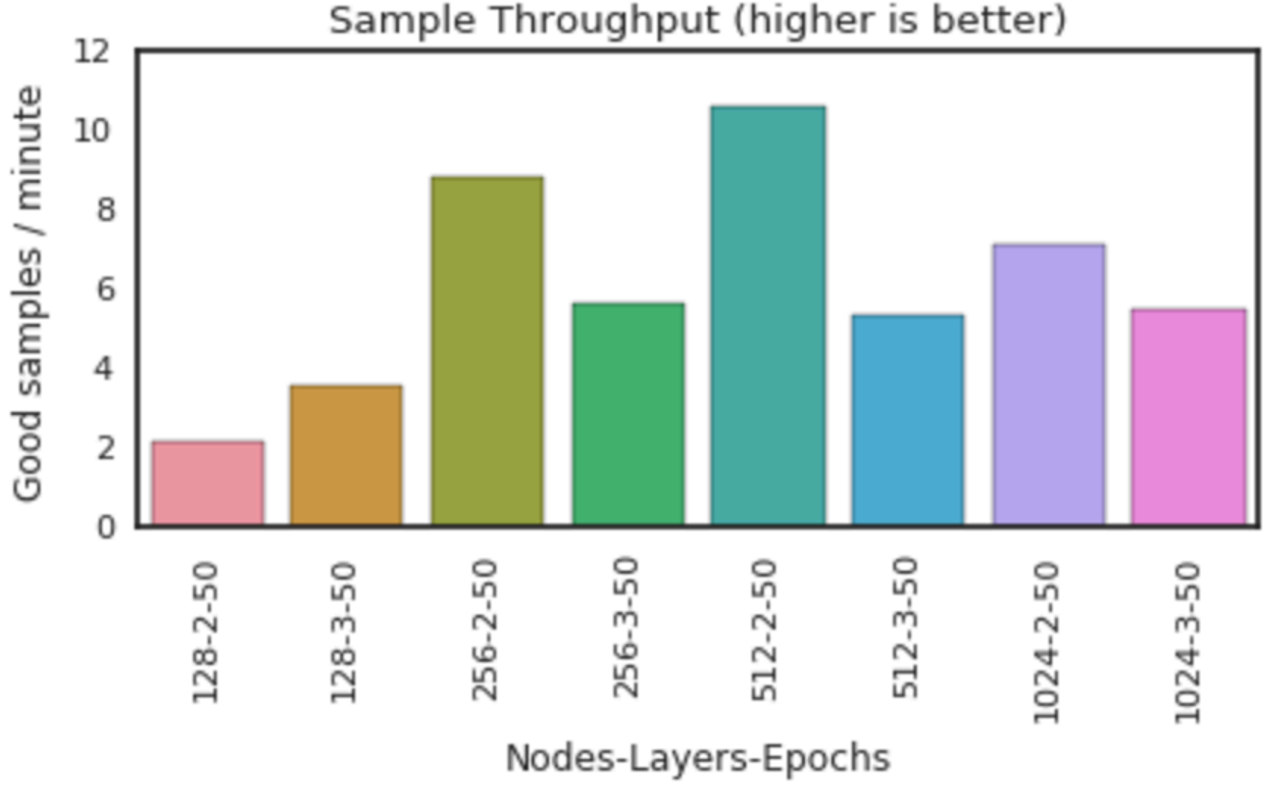
	Version	#. benchmarks	#. kernels
NPB (SNU [29])	1.0.3	7	114
Rodinia [30]	3.1	14	31
NVIDIA SDK	4.2	6	12
AMD SDK	3.0	12	16
Parboil [31]	0.2	6	8
PolyBench [32]	1.0	14	27
SHOC [33]	1.1.5	12	48
Total	-	71	256

Table 3. List of benchmarks.

	Intel CPU	AMD GPU	NVIDIA GPU
Model	Core i7-3820	Tahiti 7970	GTX 970
Frequency	3.6 GHz	1000 MHz	1050 MHz
#. Cores	4	2048	1664
Memory	8 GB	3 GB	4 GB
Throughput	105 GFLOPS	3.79 TFLOPS	3.90 TFLOPS
Driver	AMD 1526.3	AMD 1526.3	NVIDIA 361.42
Compiler	GCC 4.7.2	GCC 4.7.2	GCC 5.4.0

Table 4. Experimental platforms.


Sample Efficiency (higher is better)
% good samples
0
2
4
6
8
10
12
14
16
128-2-50
128-3-50
256-2-50
256-3-50
512-2-50
512-3-50
1024-2-50
1024-3-50
Nodes-Layers-Epochs


Sample Throughput (higher is better)
Good samples / minute
0
2
4
6
8
10
12
128-2-50
128-3-50
256-2-50
256-3-50
512-2-50
512-3-50
1024-2-50
1024-3-50
Nodes-Layers-Epochs

Limitations

Rejection sampling is wasteful.
No support for things declared outside of kernel scope.

Strengths

Basically* language agnostic.
35 million repos on GitHub. We're using 0.00004%.
Generates 2000 OpenCL benchmarks per machine per day.