Expectation-Oriented Framework for Automating Approximate Programming

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Approximate Programming

Programmer's

manual/explicit specification

[EnerJ PLDI'11, Rely OOPSLA'13]

AUTOMATE

approximate programming

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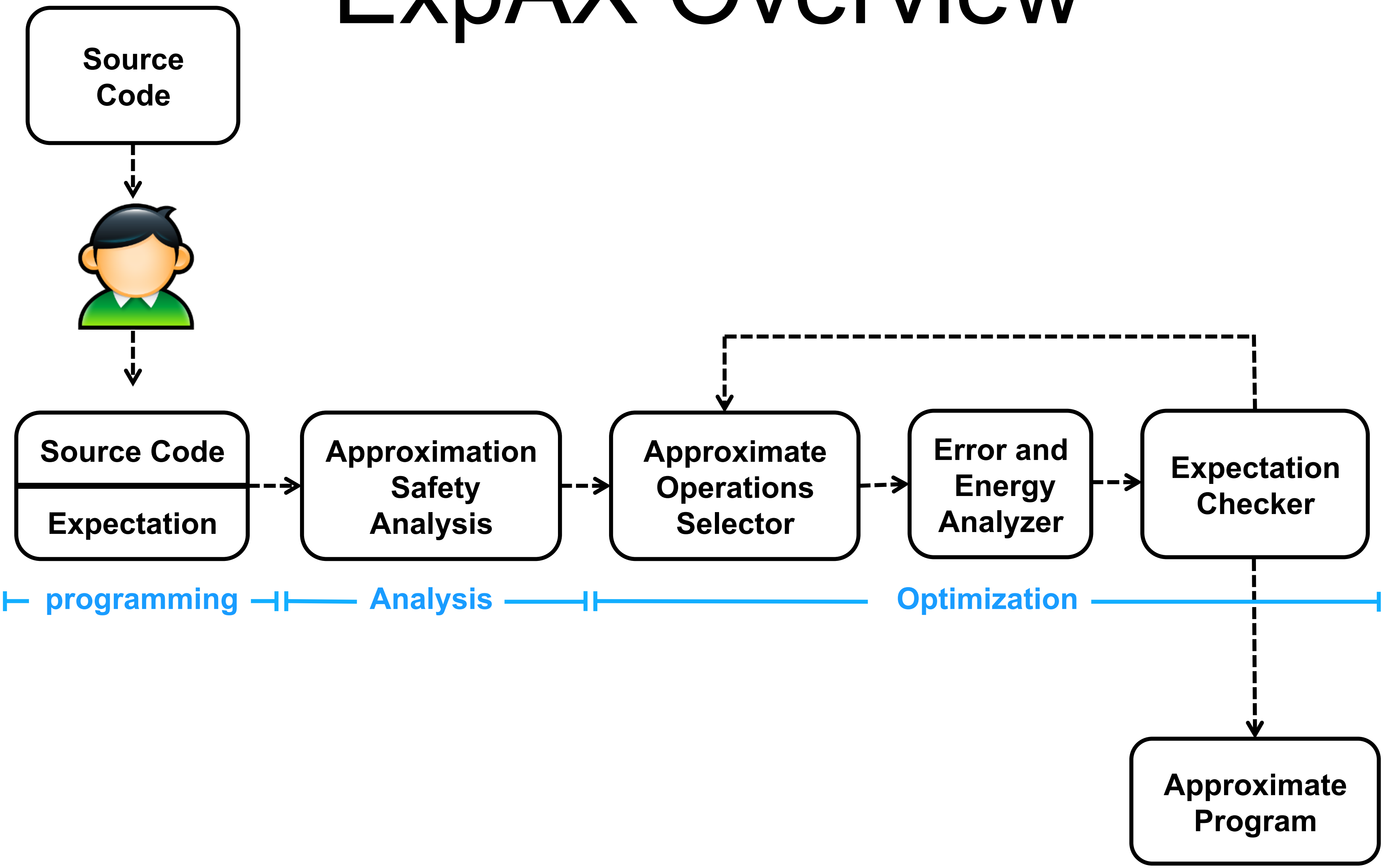
Where? How much?

ExpAX Overview



Programming Model

Programmer's Annotations with **Expectation**

1. accept rate(v) < c

   e.g. accept rate(v) < 0.2
2. accept magnitude(v) < c using f

   e.g. accept magnitude(v) < 0.1
3. accept magnitude(v) > c using f with rate < c'

   e.g. accept magnitude(v) > 0.9 with rate < 0.3

Approximation Safety Analysis

Find possible safe-to-approximate variables

Unsafe-to-approximate variables

1. Variables violating memory safety
2. Variables violating functional correctness

Approximation Safety Analysis

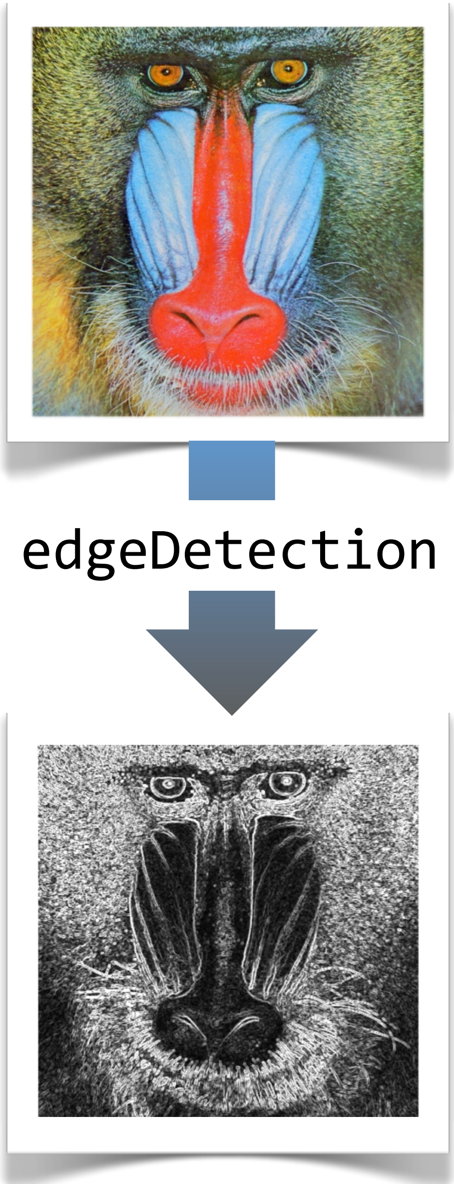
Backslicing Analysis

For each variable **v** in program,
find all variables **contributing** to the variable **v**

unsafe-to-approximate variables
should be **precise**

Everything else should be **precise** variables

Example




```
Float sobel (float[3][3] p) {
    float x, y, gradient;
    x = (p[0][0] + 2 * p[0][1] + p[0][2]);
    x += (p[2][0] + 2 * p[0][1] + p[2][2]);
    y = (p[0][2] + 2 * p[1][2] + p[2][2]);
    y += (p[0][0] + 2 * p[1][1] + p[2][0]);
    gradient = sqrt(x * x + y * y);
    ...
    return gradient;
}
```

```
void edgeDetection(Image &src, Image &dst) {
    grayscale(src);

    for (int y = …)
        for (int x = …)
            dst[x][y] = sobel(window(src, x, y));

    accept rate(dst) < 0.1;
}
```

Optimization

Find a subset of safe-to-approximate operations

- Minimize error
- Maximize energy saving

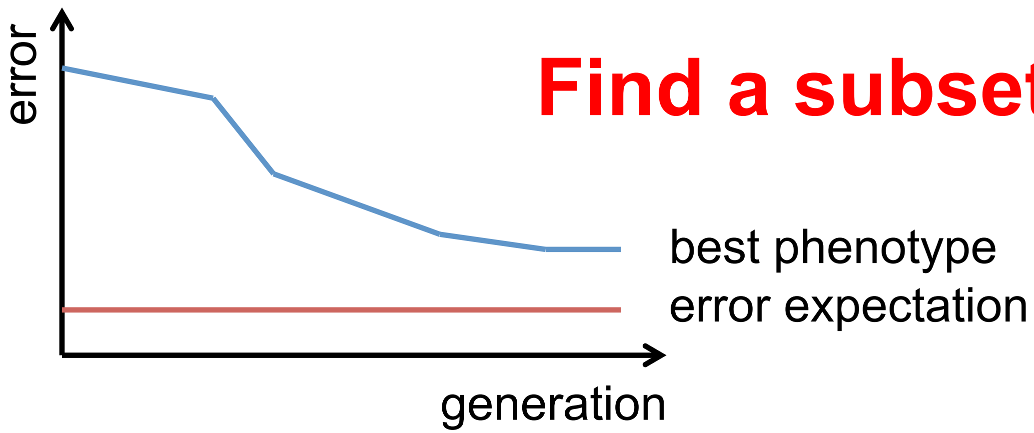
Objective function

$$f(subset) = \left(\alpha \times error + \beta \times energy\right)^{-1}$$

Genetic algorithm

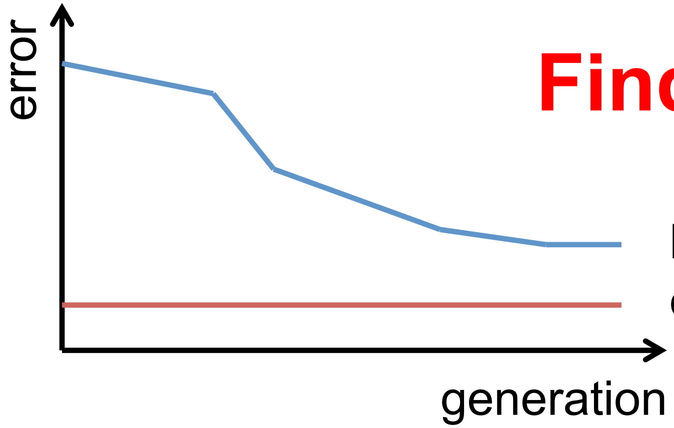
phenotype: a bitvector representing a subset (approximate('0') or precise('1'))

Statistical Guarantee



Find a subset of best phenotype!

Statistical Guarantee

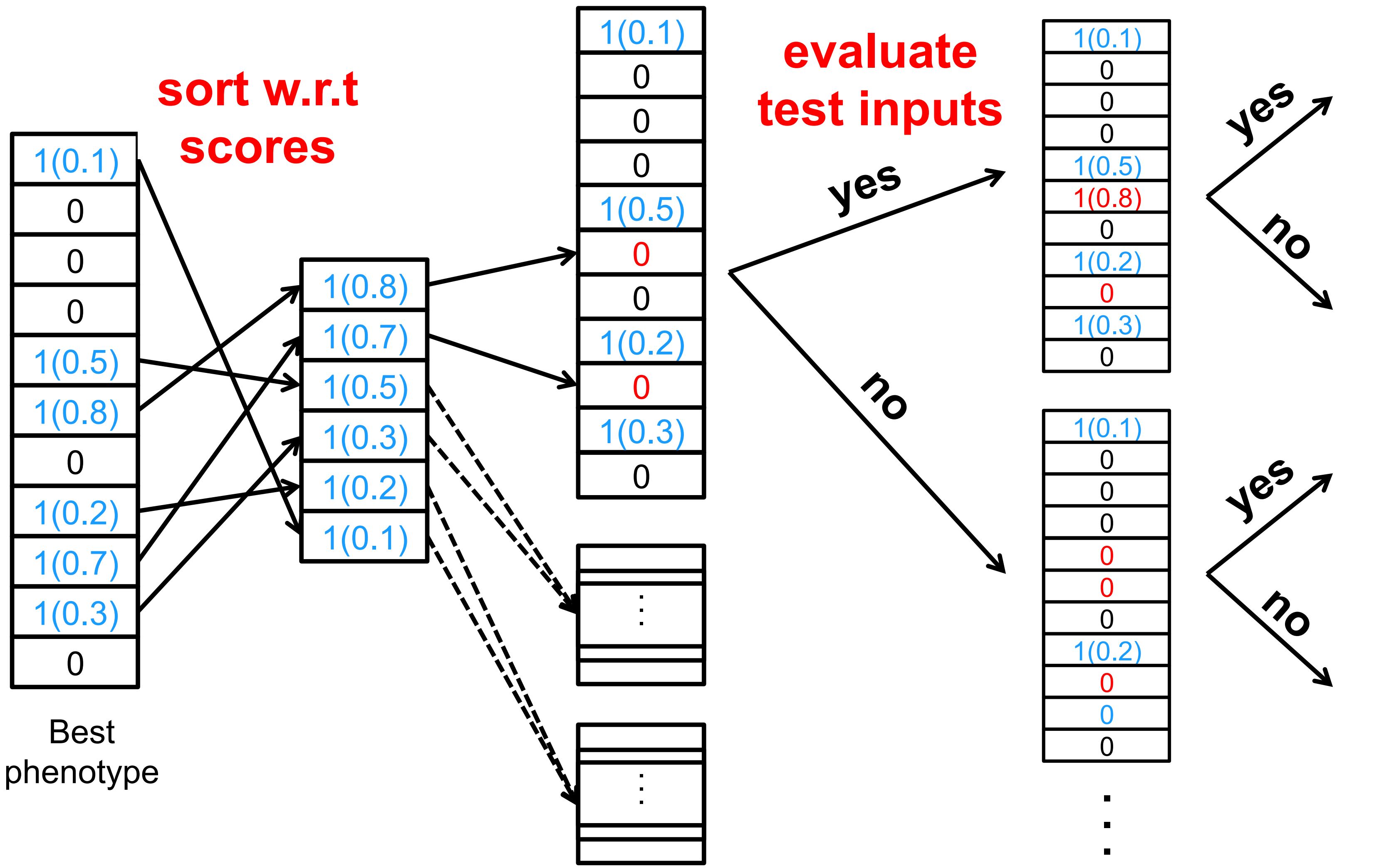


Find a subset of best phenotype!

For each eval in genetic algorithm:
calculate a score for each operation

$$f(operation) = \sum_{eval \in Eval} \left(\frac{\alpha \times error + \beta \times energy}{n(approx)} \right) \ / \ n(Eval)$$

Space Exploration with Transformed Best Phenotype



Evaluation

Benchmarks:
scimark2 – FFT, LU, SOR, MonteCarlo, SMM
Imagefill, raytracer, jmeint, zxing

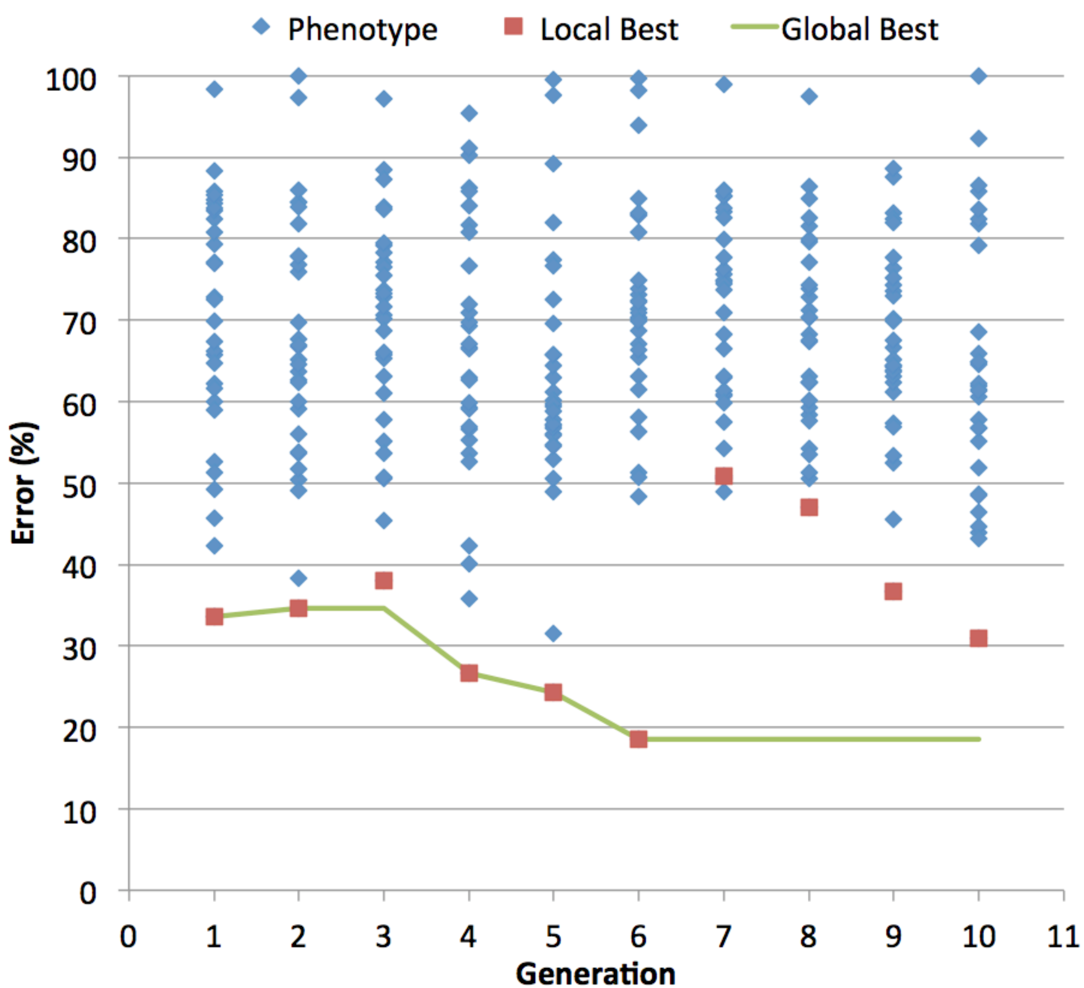
Analysis tool:
Jchord – Open source programming analysis platform for Java

Simulator:
Open-source simulator provided by EnerJ

Analysis Result

BenchName	Enerj: # of Annotations	ExpAX: # of Expectations
FFT	**27**	**1**
LU	**20**	**1**
SOR	**9**	**1**
MonteCarlo	**3**	**1**
SMM	**8**	**1**
imagefill	**28**	**7**
RayTracer	**27**	**2**
jmeint	**113**	**1**
zxing	**172**	**15**

Genetic Algorithm Results



LU

Conclusion

Expax:
an expectation-oriented framework for automating approximate programming

1. Programming model with a new program specification
2. Approximation safety analysis
3. Optimization framework
   with heuristics for statistical guarantee