Vobla: A Vehicle for Optimized Basic Linear Algebra

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OpenCL on embedded/mobile devices

Performance improvements

- Power consumption
- Execution time

Example of applications

- Image and video processing
- Signal processing
- Physics engines

Programmer Productivity

- Optimized accelerator code is tedious to write.
- Algorithm becomes tightly coupled with implementation.
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Example OpenCL code for cgemm:

```
...
float4 accum_real = (float4)(0,0,0,0);
float4 accum_img = (float4)(0,0,0,0);
for (int c4 = 0; c4 < k; c4 += 2) {
  float4 aa = vload4(0, (global float*)&A[i * n + c4]);
  float4 bb;
  bb.s01 = vload2(0, (global float*)&B[c4*k + j]);
  bb.s23 = vload2(0, (global float*)&B[(c4 + 1)*k + j]);
  accum_real += aa * bb;
  accum_img += aa * bb.s1032;
}
...
```

Performance Portability

- OpenCL is functionally portable, but not *performance portable*.
- Code optimized for device A performs poorly on device B.
- In fact, some code may not run at all on a different device (e.g. out of resources).

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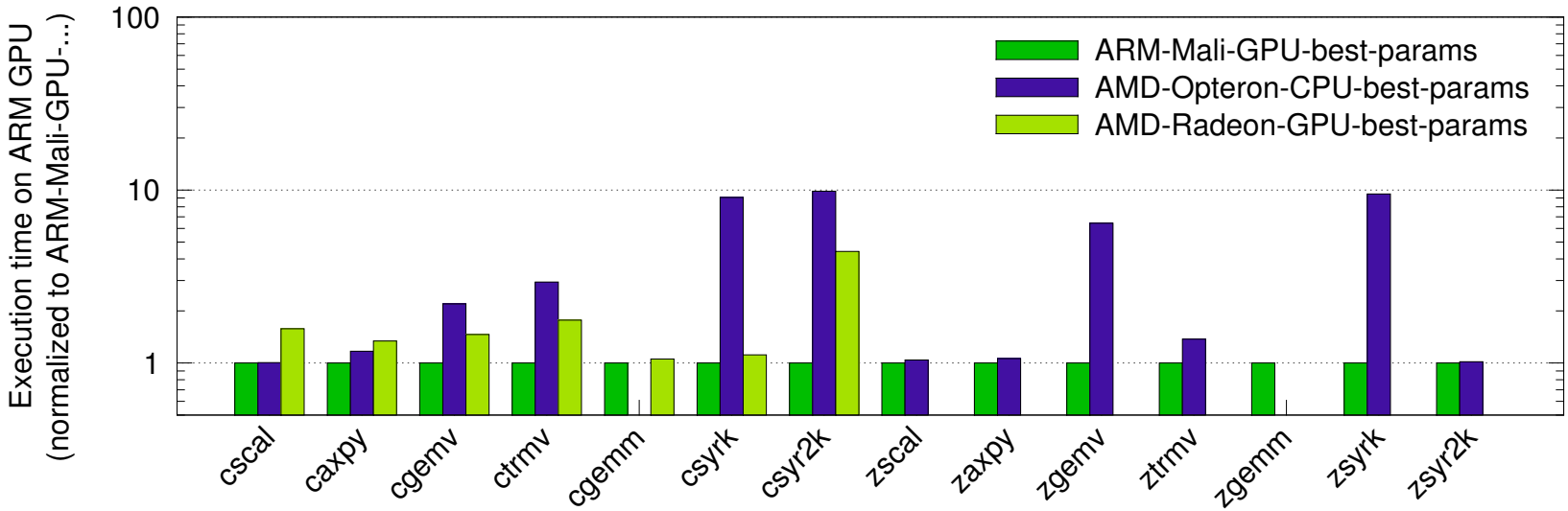
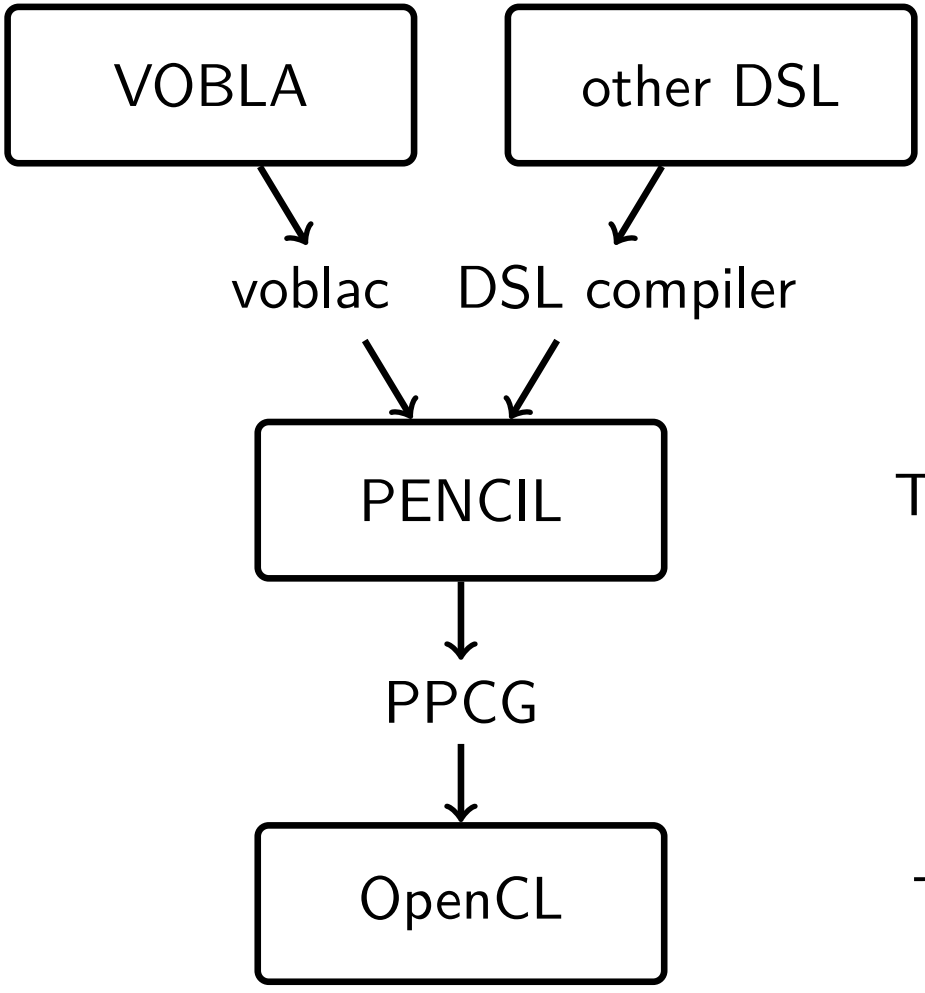


Solution



Domain specific

Easy to write

Target and domain independent

Harder to write

Target specific optimized code

Very hard to write

DSL Level: Extracting the Algorithm

Algorithmic concerns

$$Y \leftarrow \alpha AX + \beta Y$$

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Non-algorithmic concerns

- Dense or sparse matrix
- Single or double precision
- Real or complex
- Storage format
- Loop tiling size
- Vectorization factor
- ...

Export statements

Generic algorithm

```
// In function foo
Yi *= beta forall _, Yi in Y.sparse;
Y[i] += alpha*Aij*X[j] for i, j, Aij in A.sparse;
```

Specialization

```
export foo<Double>(A is Array) as dfoo_dense;
export foo<Complex Float>(A is Csr) as cfoo_csr;
```

Access patterns

6	0	3	2
0	4	7	2
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- Enumerate all the elements

```
Aij = i * j forall i, j, Aij in A;
```

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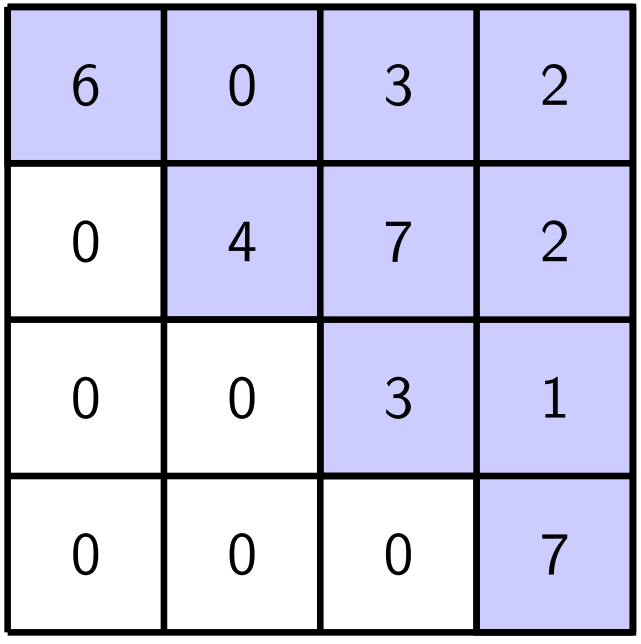

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Sparse Iterate

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- Skip zeros when possible

```
norm2 += Xi * Xi for _, Xi in X.sparse;
```

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```

Random Access

- Access by element index

```
dot += xi * y[i] forall i, xi in X.sparse;
```

Array operators

Array operators

- `=`, `+`, `-`, `*`, `/`, `sum` operators available
- Use the best access pattern available

Example

```
// Original code
X *= 2;

// Compiled code
Xi *= 2 forall _, Xi in X.sparse;
```

Data views

Matrix transposition for free

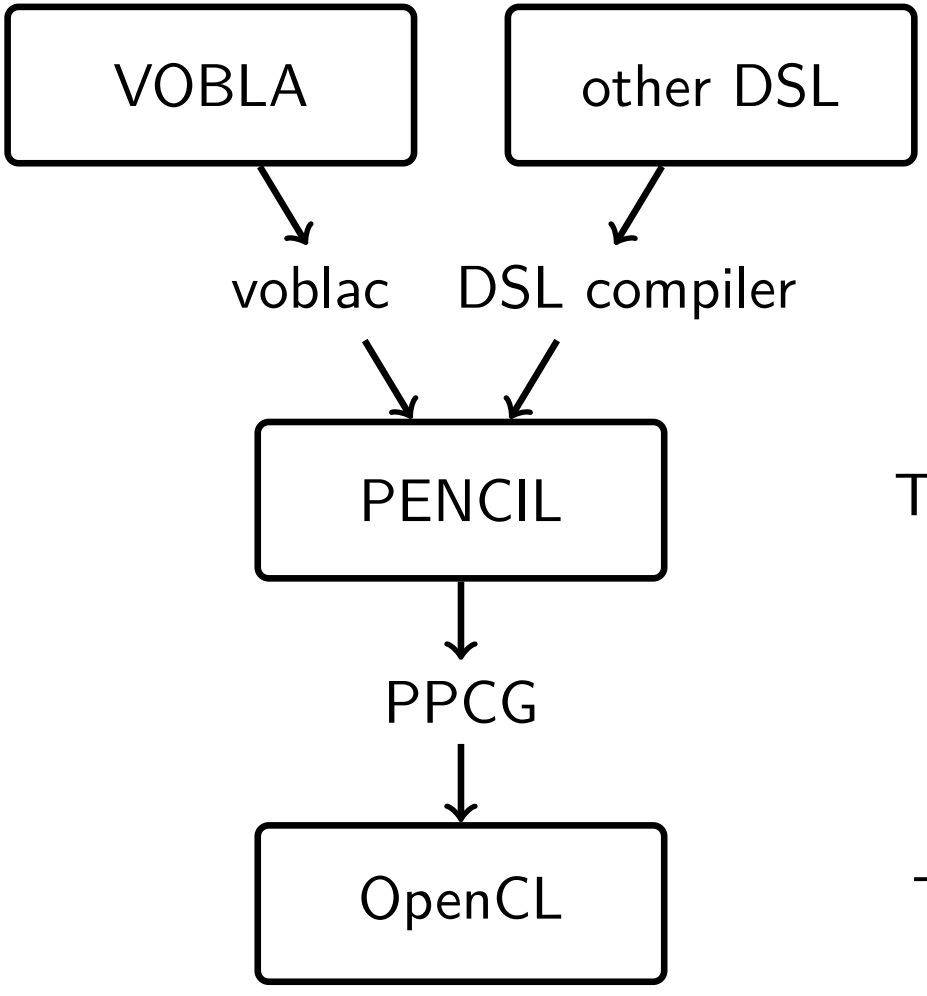
```
// Original code
x = Transpose(B)[i][j]
```

```
// Compiled code
x = B[j][i]
```

Features

- Also handle submatrices, row extraction, conjugate
- Views can be combined
- User can define new views

Code generation



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Pencil to OpenCL

Expected features of the Pencil compiler

- Generates both GPU and CPU code
- Handle data transfers between the GPU and the CPU
- Generates efficient parallel code

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Polyhedral compilation

- Automatic parallelization
- Well suitted for massive data parallelism
- Only works for regular access patterns

Pencil code generation from Vobla

Generates polyhedral-friendly code

- Array iterators and operators
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Expose information on arrays

- Keep track of array size to copy them to the GPU memory
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- Track aliasing

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Explicit parallelization by the programmer

- Use `for` to let the compiler find parallelism
- Use `forall` to indicate parallelism of irregular code

Example: Gemv

Generic Matrix-Vector multiplication:

$$\boldsymbol{Y} \leftarrow \alpha \times \boldsymbol{A} \times \boldsymbol{X} + \beta \times \boldsymbol{Y}$$

Example: Gemv

```
import sparse.csr;

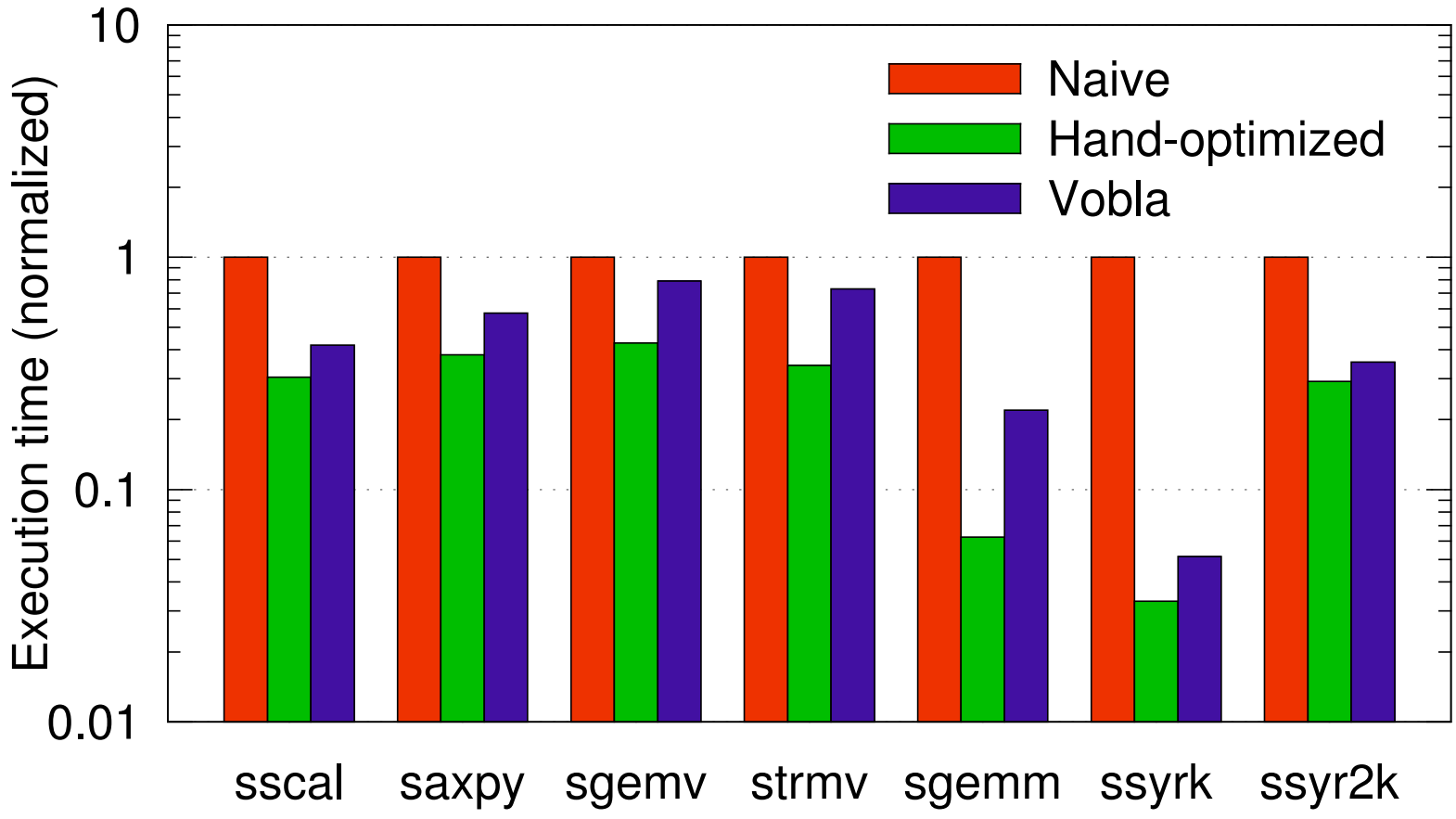
function gemv(
    alpha: Value,
    in A: SparseIterable<Value>[m][n],
    in X: Value[n],
    beta: Value,
    out Y: Value[m]) {
  // Y = beta * Y
  Y *= beta;
  // Y += A * X
  Y[i] += alpha*Aij*X[j] for i, j, Aij in A.sparse;
}

export gemv<Complex Float>(A is Csr) as gemv_csr;
```

Example: Gemv

```
void cgemv_csr(
    const struct ComplexFloat alpha,
    const struct Csr_view A_view,
    const int A_colIdx[restrict const static A_view.storage.nNonZero],
    const int A_rowPtr[restrict const static A_view.storage.nRows+1],
    const struct ComplexFloat A_data[restrict const static A_view.storage.nNonZero],
    const struct VectorView X_view,
    const struct ComplexFloat X[restrict const static X_view.storage.base_size0],
    const struct ComplexFloat beta,
    const struct VectorView C_view,
    struct ComplexFloat Y[restrict const static C_view.storage.base_size0]) {
  __pencil_assume((X_view.view_size0==A_view.storage.nCols));
  __pencil_assume((C_view.view_size0==A_view.storage.nRows));
#pragma pencil independent
  for(int i = 0; i <= C_view.view_size0-1; i += 1) {
    struct ComplexFloat tmp;
    tmp.Re = Y[C_view.offset0+i].Re * beta.Re - Y[C_view.offset0+i].Im*beta.Im;
    tmp.Im = Y[C_view.offset0+i].Im * beta.Re + Y[C_view.offset0+i].Re*beta.Im;
    Y[C_view.offset0+i] = tmp;
  }
  for(int i = 0; i <= A_view.storage.nRows-1; i += 1) {
    for(int j = A_rowPtr[i]; j <= A_rowPtr[i+1]-1; j += 1) {
      struct ComplexFloat AXpY;
      struct ComplexFloat alphaA;
      struct ComplexFloat alphaAX;
      alphaA.Re = alpha.Re*A_data[j].Re - alpha.Im*A_data[j].Im;
      alphaA.Im = alpha.Im*A_data[j].Re + alpha.Re*A_data[j].Im;
      alphaAX.Re = alphaA.Re*X[X_view.offset0+A_colIdx[j]].Re - alphaA.Im*X[X_view.offset0+A_colIdx[j]].Im;
      alphaAX.Im = alphaA.Im*X[X_view.offset0+A_colIdx[j]].Re + alphaA.Re*X[X_view.offset0+A_colIdx[j]].Im;
      AXpY.Re = Y[C_view.offset0+i].Re + alphaAX.Re;
      AXpY.Im = Y[C_view.offset0+i].Im + alphaAX.Im;
      Y[C_view.offset0+i] = AXpY;
    }
  }
}
```

Results on Mali-T604 GPU



Contributions

Vobla DSL

- Generic code that can be specialized into many versions
- Concise code that only exposes algorithmic concerns
- Support for user-defined storage formats

BLAS implementation

- 8× improvement over straightforward OpenCL code
- Compliant with the original implementation

Pencil compilation flow validation

- Working toolchain from Vobla to OpenCL

Thank you!

Get the source code:

http://github.com/carpproject

Learn more about the CARP project:

http://carpproject.eu