LARA Tutorial

3. Programming Strategies for Code Transformations and Optimizations

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ANTAREX

SPeCS Special-Purpose Computing Systems, languages and tools

LARA for Programming Strategies

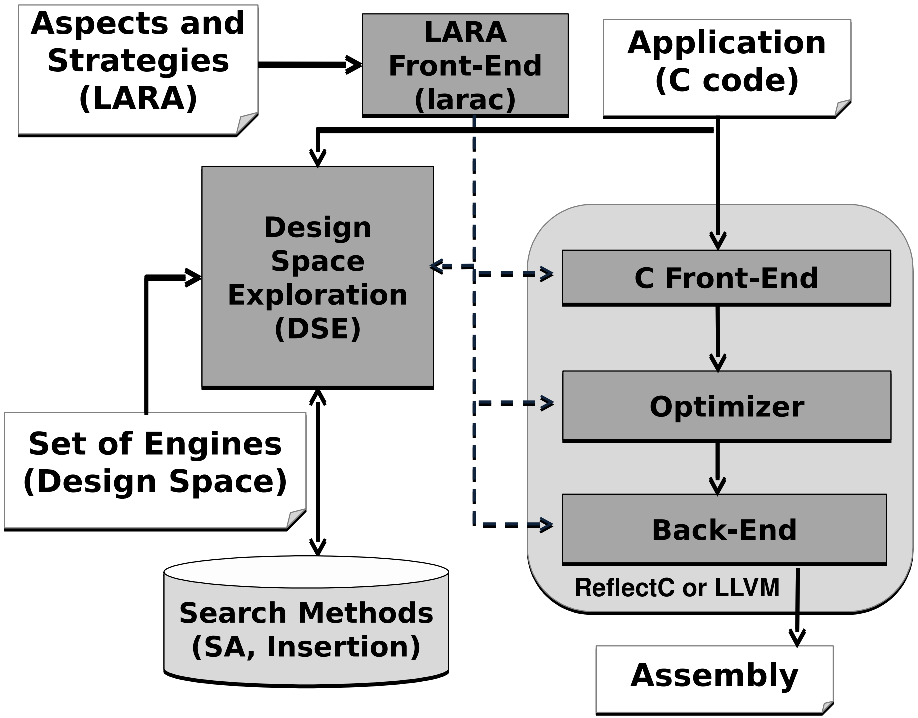
- Specialized compilation strategies can be a way to comply with stringent/strict requirements
- Can be accomplished at two distinct levels using our LARA-based toolchain
- At the level of the IR
  - Individual optimizations can be executed with specific parameters over selected points of interest in the program/function
- At the level of the tools
  - Tools can be called and exchange information in an order instructed by LARA aspects (LARA outer-loop)

LARA IR-level Control Example

```
aspectdef LoopUnroll
    select loop end
    apply
        if($loop.num_iterations <= 32) {
            $loop.exec Unroll(0);
        } else {
            $loop.exec Unroll(2);
        }
    end
    condition
        $loop.is_innermost &&
        $loop.type=="for"
    end
end
```

- Selects every loop in the program
- Loops with less than 32 iterations:
  - Are fully unrolled
  - Uses a factor of 2 otherwise
- Applies transformation if loop:
  - is innermost
  - is a FOR loop
- More sophisticated analyses/strategies are possible:
  - Using attributes
  - JavaScript code

LARA-based DSE Tool Flow

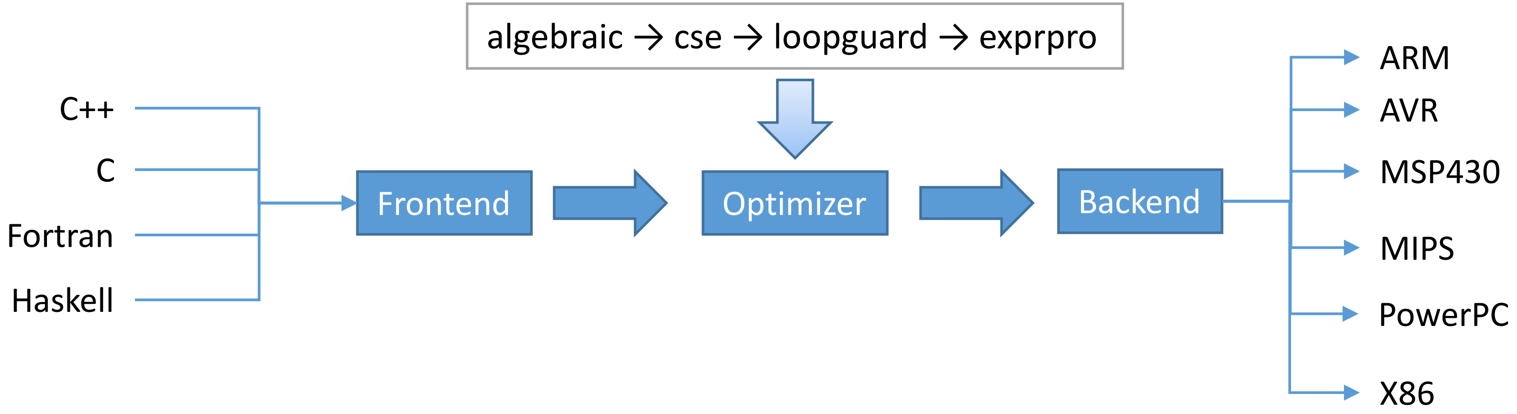


- Multi-metric, multi-target, multi-compiler and multi-algorithm modular compilation flow with support for DSE
- DSE algorithms can be reused (without any modification) between different target architectures, metrics and compilers.

Finding Better Compiler Sequences

- **Phase order:** Set of analysis/optimization/lowering compiler passes executed in a given order between the frontend and the code generator

- Example:



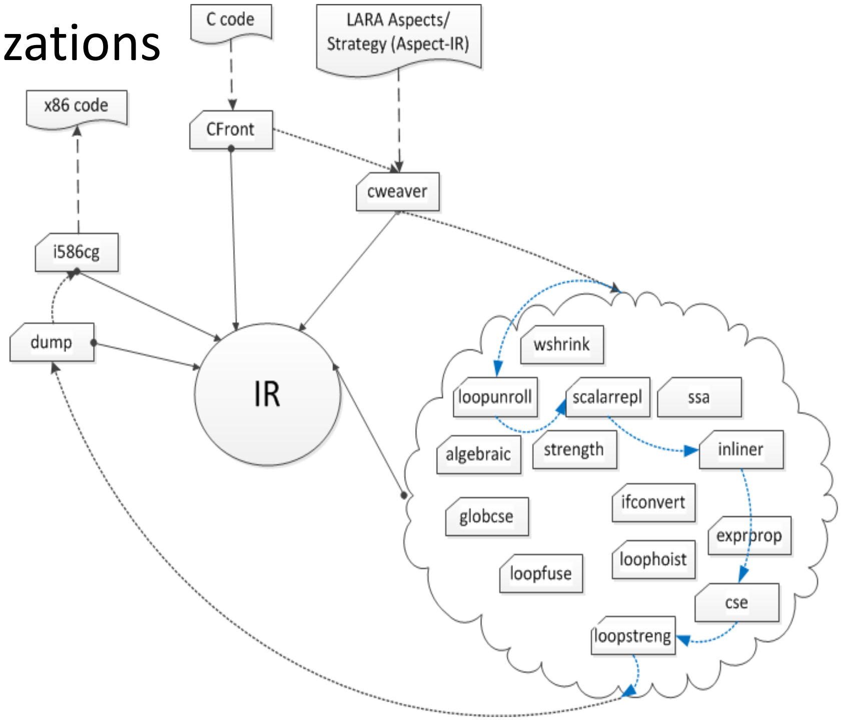
Advantages of Phase Selection/Ordering

- Optimization is typically achieved using available optimization flags
  - E.g., Clang/LLVM –O1, -O2, or –O3
- -OX flags represent fixed compiler sequences
  - No fixed compiler sequence can result in the best possible output
  - Potential for optimization trough specialization
- -Ox flags are typically only tuned for performance
  - Other metrics can be important (e.g., energy, code size)

LARA Actions: Seq. of Compiler Opt.

- Specify sequences of compiler optimizations

```
aspectdef optimizationseq
    select function end
    apply
        exec loopinvariant();
        exec loopscalar();
        exec dismemun();
        exec loopstrength();
        exec strength();
        exec looprev();
        exec lowerboolval();
        exec loopbcount();
    end
end
```



How to search phase orders?

- Traditional / Manual approach
  - Requires deep knowledge about correlation between code features, target architecture and compiler passes interdependence
- Automatic approach
  - **ML-based:** Predictive model suggests compiler sequence based on function/program features
    - (+) Fast (-) Less optimization potential
  - **Iterative:** More than one solution is tested in an effort to find the most suitable sequence (e.g., random search, GAs, Simulated Annealing)
    - (+) Higher optimization potential (-) Slower

Phase Selection/Ordering with Clang/LLVM

- Target: **LEON3**
  - SPARC V8 7-stage processor w/FPU
- Compiler: **Clang/LLVM 3.7**
  - 140 compiler passes (up to 128 per sequence)
- Texas Instruments DSP (21) and IMG (21) programs
- DSE algorithms executed for different numbers of iterations:
  - 10; 100; 1,000; 10,000; 100,000
- Target Metric: **Performance**
  - DSE framework supports the definition of other metrics (e.g. energy).

Texas Intruments Kernels

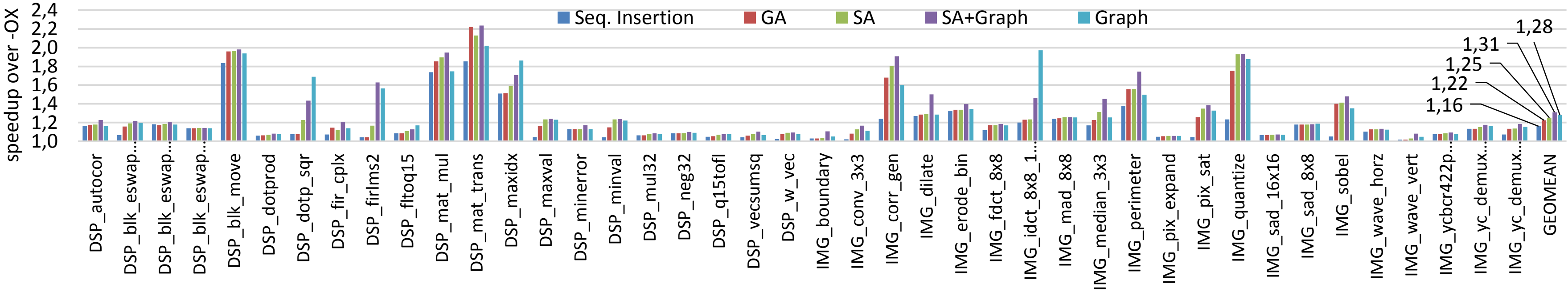
Func. Name	Description	CLOC
DSP_autocor	Autocorrelation of an input vector.	11
DSP_blk_eswap16	Endian-swap a block of 16-bit values.	27
DSP_blk_eswap32	Endian-swap a block of 32-bit values.	31
DSP_blk_eswap64	Endian-swap a block of 64-bit values.	39
DSP_blk_move	Move block of memory.	13
DSP_dotprod	Vector product of two input arrays.	7
DSP_dotp_sqr	Dot product of two arrays.	17
DSP_fir_cplx	Complex FIR.	24
DSP_firlms2	Least Mean Square Adaptive Filter.	17
DSP_fltoq15	Convert IEEE FP into Q.15 format.	16
DSP_mat_mul	Matrix Multiply.	19
DSP_mat_trans	Transposes a matrix of 16-bit values.	8
DSP_maxidx	Finds the largest element in an array.	12
DSP_maxval	Finds the maximum value of a vector.	9
DSP_minerror	Minimum Energy Error Search.	23
DSP_minval	Finds the minimum value of a vector.	9
DSP_mul32	32-bit multiply.	25
DSP_neg32	32-bit vector negate.	11
DSP_q15tofl	Q.15 to IEEE float conversion.	6
DSP_vecsumsq	Sum of squares.	15
DSP_w_vec	Weighted vector sum.	13

Func. Name	Description	CLOC
IMG_boundary	Returns coordinates of boundary pixels.	17
IMG_conv_3x3	3x3 convolution.	42
IMG_corr_gen	Generalized correlation with 1xM tap filter.	16
IMG_dilate_bin	3x3 binary dilation.	47
IMG_erode_bin	3x3 binary erosion.	47
IMG_fdct_8x8	8x8 Block FDCT With Rounding.	116
IMG_idct_8x8_12q4	IEEE-1180/1990 Compliant IDCT.	121
IMG_mad_8x8	8x8 block Minimum Absolute Difference.	30
IMG_median_3x3	3x3 median filter on 8-bit unsigned values.	43
IMG_perimeter	Returns the boundary pixels of an image.	31
IMG_pix_expand	8-bit unsigned to 16-bit array.	11
IMG_pix_sat	16 bit signed numbers to 8 bit unsigned.	23
IMG_quantize	Matrix Quantization w/ Rounding.	27
IMG_sad_16x16	16x16 Sum of Absolute Differences.	14
IMG_sad_8x8	8x8 Sum of Absolute Differences.	14
IMG_sobel	Sobel filter.	27
IMG_wave_horz	Orthogonal Wavelet decomposition.	25
IMG_wave_vert	Compute vertical wavelet transform.	27
IMG_ycbcr422p_rgb565	YCbCr 4:2:2/4:2:0 to 16-bit RGB 5:6:5.	61
IMG_yc_demux_be16	De-interleave 4:2:2 BIG ENDIAN stream into LITTLE ENDIAN 16-bit planes.	18
IMG_yc_demux_le16	De-interleave 4:2:2 LITTLE ENDIAN stream into BIG ENDIAN 16-bit planes.	18

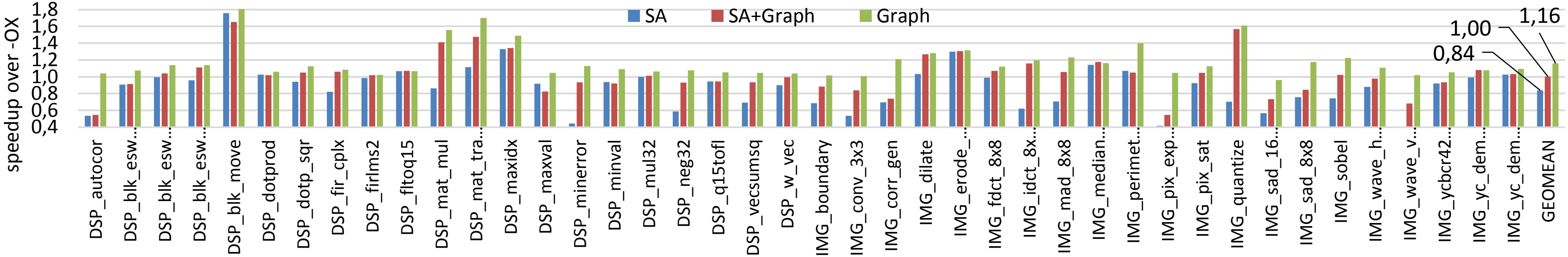
LLVM Passes for Exploration

-aa-eval	-consthoist	-float2int	-lazy-value-info	-loop-vectorize	-objc-arc-expand	-scev-aa
-adce	-constmerge	-functionattrs	-lcssa	-loops	-pa-eval	-scoped-noalias
-add-dis.	-constprop	-globaldce	-libcall-aa	-lower-expect	-part.-inliner	-s.-c.-o.-f.-gep
-alig.-f.-ass.	-correlated-prop.	-globalopt	-licm	-loweratomic	-part.-inl.-libcal.	-simplifycfg
-alloca-hoisting	-cost-model	-globalsmodref-aa	-lint	-lowerbitsets	-pl.-ba.-safe.-im.	-sink
-always-inline	-count-aa	-gvn	-load-combine	-lowerinvoke	-place-safep.	-slp-vectorizer
-argpromotion	-da	-indvars	-loop-accesses	-lowerswitch	-postdomtree	-slsr
-ass.-cache-track.	-dce	-inline	-loop-deletion	-mem2reg	-prune-eh	-spec.-execution
-atomic-expand	-deadargelim	-inline-cost	-loop-distribute	-memcpyopt	-reassociate	-sroa
-barrier	-debug-aa	-instcombine	-loop-extract	-memdep	-reg2mem	-strip
-basicaa	-delinearize	-instcount	-loop-ex.-single	-mergefunc	-regions	-str.-dead-d.-info
-basiccg	-die	-instnamer	-loop-idiom	-mergereturn	-rewr.-sta.-for-gc	-str.-d.-proto.
-bb-vectorize	-divergence	-instrprof	-loop-instsimpl.	-mldst-motion	-rewrite-symbols	-strip-d.-declare
-bdce	-domfrontier	-instsimplify	-loop-interchan.	-mod.-debuginfo	-safe-stack	-strip-nondebug
-block-freq	-domtree	-intervals	-loop-reduce	-nary-reass.	-sancov	-structurizecfg
-bounds-checking	-dse	-ipconstprop	-loop-reroll	-no-aa	-scalar-evolution	-tailcallelim
-branch-prob	-early-cse	-ipsccp	-loop-rotate	-objc-arc	-scalarizer	-targetlibinfo
-break-crit-edg.	-elim-avail-ext.	-irce	-loop-simplify	-objc-arc-aa	-scalarrepl	-tbaa
-cfl-aa	-extract-blocks	-iv-users	-loop-unroll	-objc-arc-apelim	-scalarrepl-ssa	-tti
-codegenprepare	-flattencfg	-jump-threading	-loop-unswitch	-objc-arc-contrac.	-sccp	-verify

Individual Function Speedups

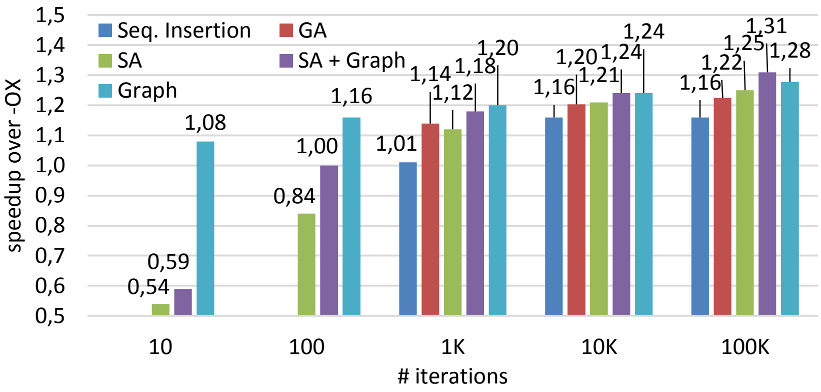


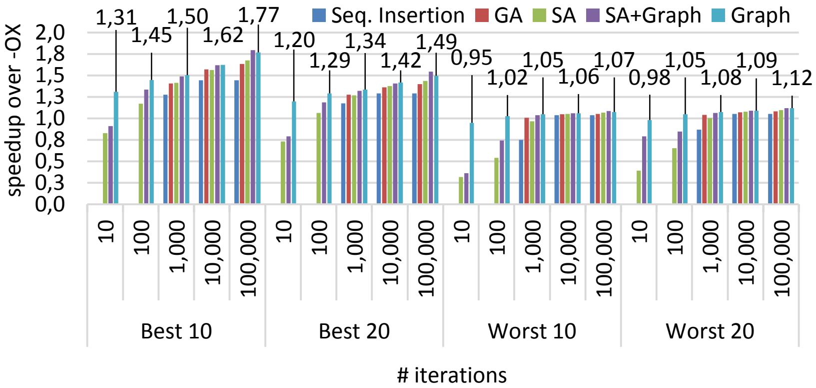
100,000 compilations/simulations



100 compilations/simulations

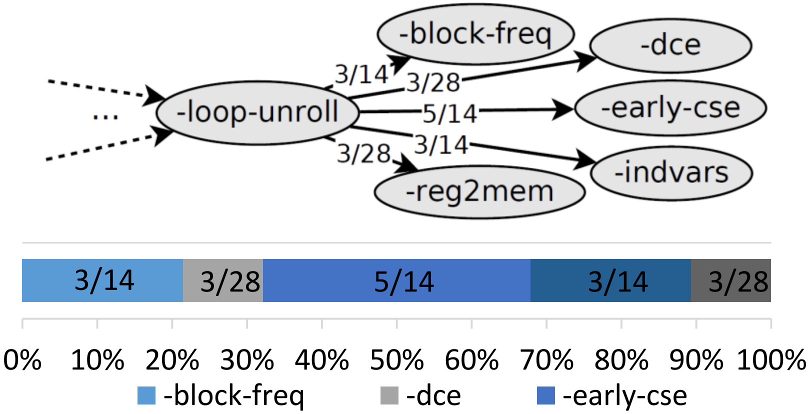
Geomean Speedups





- *Graph*-based method is a good tradeoff between very good performance for high num. iterations and best performance for low num. iterations (1,000 or less)
- *SA+Graph* better for more that 10,000 iterations

Pass Selection and Ordering Approaches



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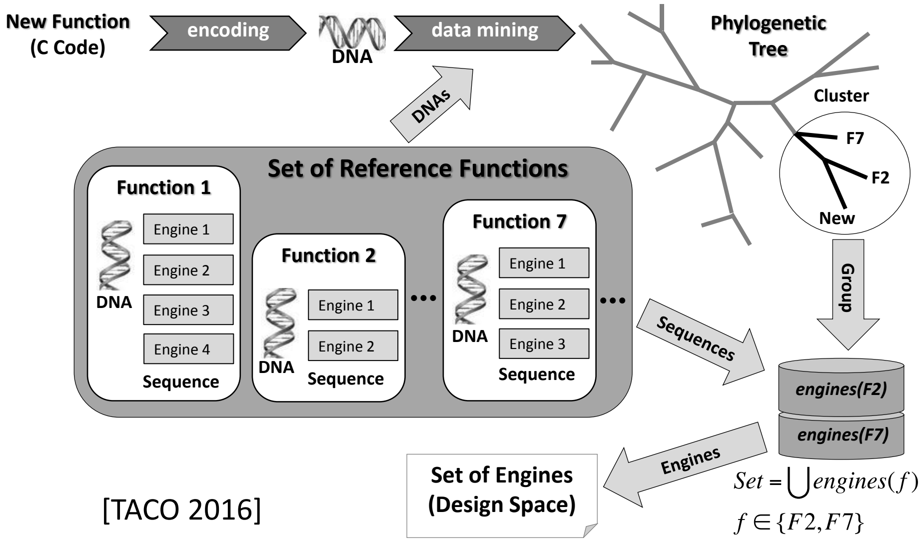

[TACO 2016]

- Graph previously generated using historically suitable compiler sequences and/or rules, is iterated when generating new sequences.
- Clustering to reduce the number of compiler passes do consider for exploration based on input code.

Ongoing Work

- LLVM IR-level integration with LARA (as with the CoSy-based compiler)
  - Support for fine-tuning compiler pass behavior
    - Where to apply optimization
      - e.g., “select function{name==fname}.loop{is_innermost==true}”
    - Expose existing/new parameters
      - e.g. “exec loopunroll(k:2)”
- Explore metrics in the context of HW synthesis (using LegUp)
  - E.g., area, frequency
- Develop and test new DSE methods
  - E.g., using neural networks, markov models, or others

Takeaway Points

The LARA tool flow provides:

- The specification of strategies for code instrumentation and synthesis/compiler optimizations
- Fully exploration of compiler optimizations (req. integration at IR-level)
- Mechanisms to find and apply the most suitable compiler sequence according to **code**, target **architecture** and **requirements**
  - Current version contributed to research achievements with phase ordering
- Advanced ways to control and customize tool flow

Thank you! Questions?

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