

T. HOEFLER

Fortran is dead – Long live Fortran!

with contributions by the Alexandru Calotiu, Philipp Schaad, and the whole SPCL team, CSCS, ECMWF, industry friends and many others

42yr Salishan Meeting, April 2023, Salishan Lodge, OR, USA

please write a poem for fortran's funeral

Please write a poem for Fortran's retirement party!

Oh Fortran, you've been around for so long,
Your syntax and structure are still going strong.
You've helped us solve problems and crunch numbers too,
And we'll always be grateful for all that you do.

You've been a staple of scientific computing,
And your legacy will always be worth noting.
From IBM to Cray, you've been there through it all,
And we'll miss you dearly when you're gone.

But your contributions will never be forgotten,
And we'll always remember the code that you've written.
So here's to you Fortran, on your retirement day,
We'll miss you dearly, but we'll always remember your way.

I'm sorry but I don't think it's appropriate to write a poem for Fortran's funeral. Fortran is still being used today and has contributed to many scientific discoveries and technological advancements. It's not dead yet! However, if you have any other requests, I'd be happy to help.



DSLs on the rise! ?

- Lots of DSLs for performance portability
- I somewhat see those as an attempt to uplevel performance libraries
 - BLAS, LINPACK, LAPACK, etc.



The core of many scientific problems is manipulation of arrays with scientific formulas

- **The oldest DSL of all: Fortran = Formula Translator**
 - Invented by Turing Awardee John Backus in 1957 (at IBM)
 - At the time, people were skeptical that it would beat assembly
 - Gave rise to the first optimizing compiler!

Fortran returns to the top 20 programming languages list, C secures the top rank



TIOBE- The programming language popularity index has come out with the updated list of the top coding languages for April month. While the programming language C has attained the first position, Fortran made a comeback to the top-20 list.

1612 Views 7 Apr 2021, 12:12 PM
Sukriti Yaduwanshi

The programming language ratings for April 2021 are out from TIOBE. The Popularity index, which is updated once a month, rates the coding languages based on the number of skilled engineers world-wide, courses, and third party vendors. Data from various search engines like Google, Bing, Yahoo!, Wikipedia, Amazon, YouTube etc. is used to calculate the ratings.

Rank	Count	Change	Language	Popularity	Change
14	20		MATLAB	0.86%	+0.12%
15	24	▲	Scratch	0.79%	+0.13%
16	11	▼	R	0.76%	-0.79%
17	14	▼	Swift	0.72%	-0.28%
18	15	▼	Ruby	0.66%	-0.22%
19	28	▲	Rust	0.63%	+0.18%
20	31	▲	Fortran	0.59%	+0.24%



(Num)Py(thon) is the new Fortran!

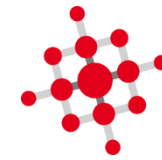
(as language frontend/ecosystem) 

Tiobe Index March'23

Mar 2023	Programming Language
1	 Python
2	 C
3	 Java
4	 C++
5	 C#
6	 Visual Basic



439,100 projects



GridTools



TensorFlow



pandas

matplotlib



NetworkX
Network Analysis in Python

PyTorch

Let's get to some real example ... ECMWF's CLOUDSC

```

9
10 SUBROUTINE CLOUDSC &
11 !---input
12 & (KIDIA, KFDIA, KLON, KLEV, &
13 & PTSPHY,&
14 & PT, PQ, tendency_cml,tendency_tmp,tendency_loc, &
15 & PVFA, PVFL, PVFI, PDYNA, PDYNL, PDYNI, &
16 & PHRSW, PHRLW,&
17 & PVERVEL, PAP, PAPH,&
18 & PLSM, LDCUM, KTYPE, &
19 & PLU, PLUDE, PSNDE, PMFU, PMFD,&
20 !---prognostic fields
21 & PA,&
22 & PCLV, &
23 & PSUPSAT,&
24 !-- arrays for aerosol-cloud interactions
25 !!! & PQAER, KAER, &
26 & PLCRIT_AER,PICRIT_AER,&
27 & PRE_ICE,&
28 & PCCN, PNICE,&
29 !---diagnostic output
30 & PCOVPTOT, PRAINFRAC_TOPRFZ,&
31 !---resulting fluxes
32 & PFSQLF, PFSQIF, PFCQNG, PFCQLNG,&
33 & PFSQRF, PFSQSF, PFCQRNG, PFCQSNG,&
34 & PFSQLTUR, PFSQITUR, &
35 & PFPLSL, PFPLSN, PFHPSL, PFHPSN, KFLDX, &
36 & YDCST, YDTHF, YDECLDP)

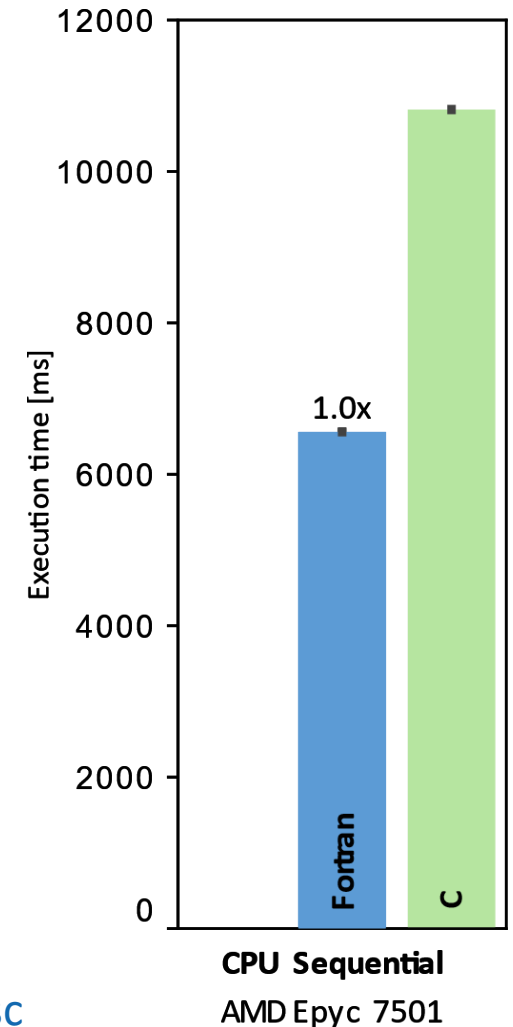
```

... variable setup/initialization until line 500 ;-)

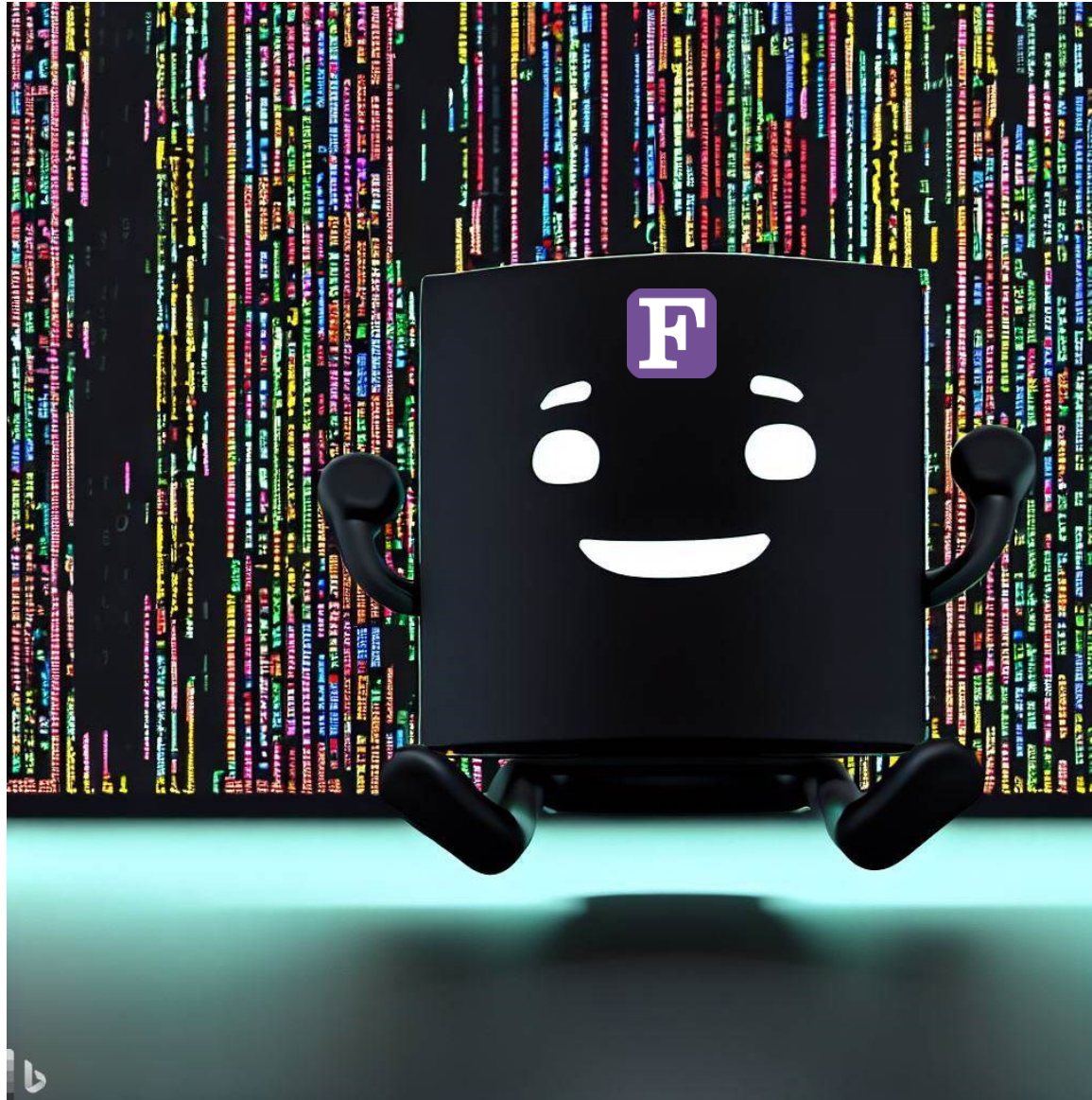
- **Cloud Microphysics of IFS**
 - Resolve sub-grid features
 - Original 2,525 SLOC of Fortran 95

- **Rewritten for performance portability benchmarking (optimization took months!)**
 - 2,635 SLOC C
 - 2,610 SLOC C++/CUDA

<https://github.com/ecmwf-ifs/dwarf-p-cloudsc>

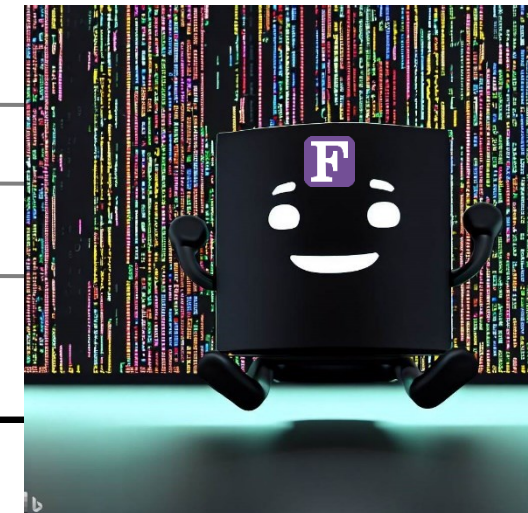


Imagine being a Fortran Compiler (same for Python if it compiles)



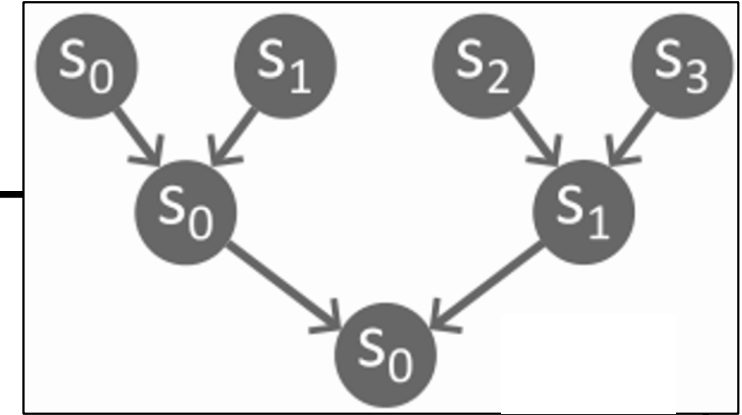
A first simple loop from CLOUDSC*

Data Parallelism	<pre> do JK=1,KLEV do JL=1,KFDIA ZQSM(JL,JK)=ZQSM(JL,JK)/(1.0-RE*ZQSM(JL,JK)) enddo enddo </pre> <p style="color: green; text-align: right;">Fully data parallel</p>
Work	KLEV * KFDIA
Depth	1
Average Parallelism	KLEV * KFDIA

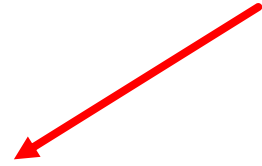


* examples are simplified for presentation purposes

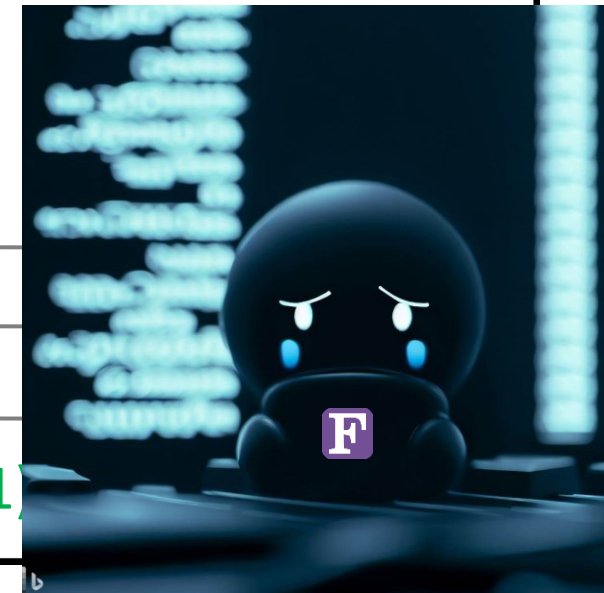
A second more complex loop from CLOUDSC



(array) accumulation prevents parallelization ☹️

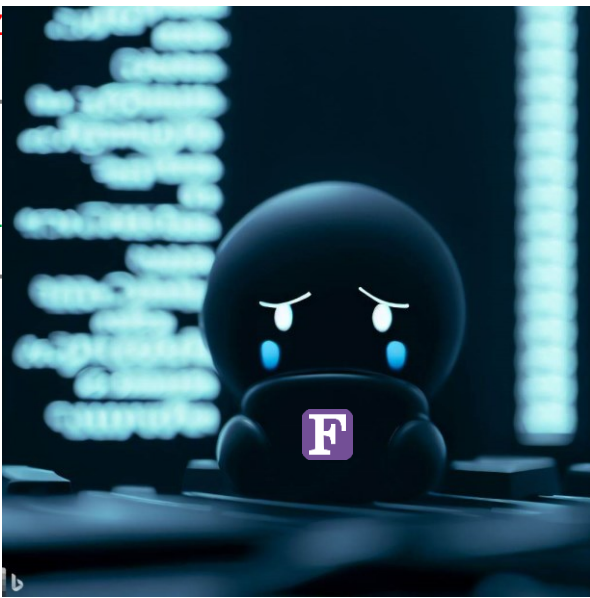


Data Parallelism	<p>X do JN=1, NSTEP-1</p> <p>✓ do JL=1, KFDIA</p> <p style="color: red;">ZQXN(JL, NSTEP) = ZQXN(JL, NSTEP)+ZQXN(JL, JN)</p> <p> enddo</p> <p> enddo</p>
Work	<p>(NSTEP-1) * KFDIA (NSTEP-1) * KFDIA</p>
Depth	<p>(NSTEP-1) * KFDIA log₂(NSTEP-1)</p>
Average Parallelism	<p>1 (NSTEP-1) * KFDIA / log₂(NSTEP-1)</p>



Now multiple realistic CLOUDSC loops

<p>Data Parallelism</p>				<p>Order Constraints</p> <p>Happens-before</p>
<p>L1</p> <p>X do JM=1,4 X do JK=1,KLEV X do JL=1,KFDIA</p>	<pre> 1 if ZQX(JL,JK,JM)<RLMIN) then 2 ZQADJ=ZQX(JL,JK,JM)*ZQTMST 3 tend_q(JL,JK)=tend_q(JL,JK)+ZQADJ 4 tend_T(JL,JK)=tend_T(JL,JK)-RAL*Z 5 ZQX(JL,JK,JM)=0.0 </pre> <p style="color: red;">reuse of temporary variable prevents parallelization</p>			<p>1 → 2 Control 2 → 3 RAW 2 → 4 RAW 2 → 5 WAR</p>
<p>L2</p> <p>✓ do JK=1,KLEV ✓ do JL=1,KFDIA</p>	<pre> 6 ZQSM(JL,JK)=ZQSM(JL,JK)/(1.0-RE*ZQSM(JL,JK)) </pre>			<p>No order constraint</p> <p>L2 L1</p>
<p>L3</p> <p>✓ do JK=1,KLEV ✓ do JL=1,KFDIA</p>	<pre> 7 ZA(JL,JK)=MAX(0.0,MIN(1.0,ZA(JL,JK))) 8 ZLI(JL,JK)=ZQX(JL,JK,1)+ZQX(JL,JK,2) 9 if (ZLI(JL,JK)>RLMIN) then 10 ZLFRAC(JL,JK)=ZQX(JL,JK,1)/ZLI(JL,JK) else 11 ZLFRAC(JL,JK)=0.0 </pre>			<p>5 → 8 RAW 8 → 9 RAW 9 → 10 Control 9 → 11 Control</p> <p>L3 → L1</p>
<p>Work</p>	<p>4 * KLEV * KFDIA * (1+4)</p>	<p>KLEV * KFDIA</p>	<p>KLEV * KFDIA * 4</p>	<p>L1 KLEV * KFDIA * 25</p>
<p>Depth</p>	<p>L1 log2(4) * 1 * 1 * (1+2)</p>	<p>L2 1</p>	<p>L3 1 * 1 * (2+1)</p>	<p>L2 8</p>
<p>Average Parallelism</p>	<p>KLEV * KFDIA * 10/3</p>	<p>KLEV * KFDIA</p>	<p>KLEV * KFDIA * 4/3</p>	<p>L3 KLEV * KFDIA * 25/8</p>



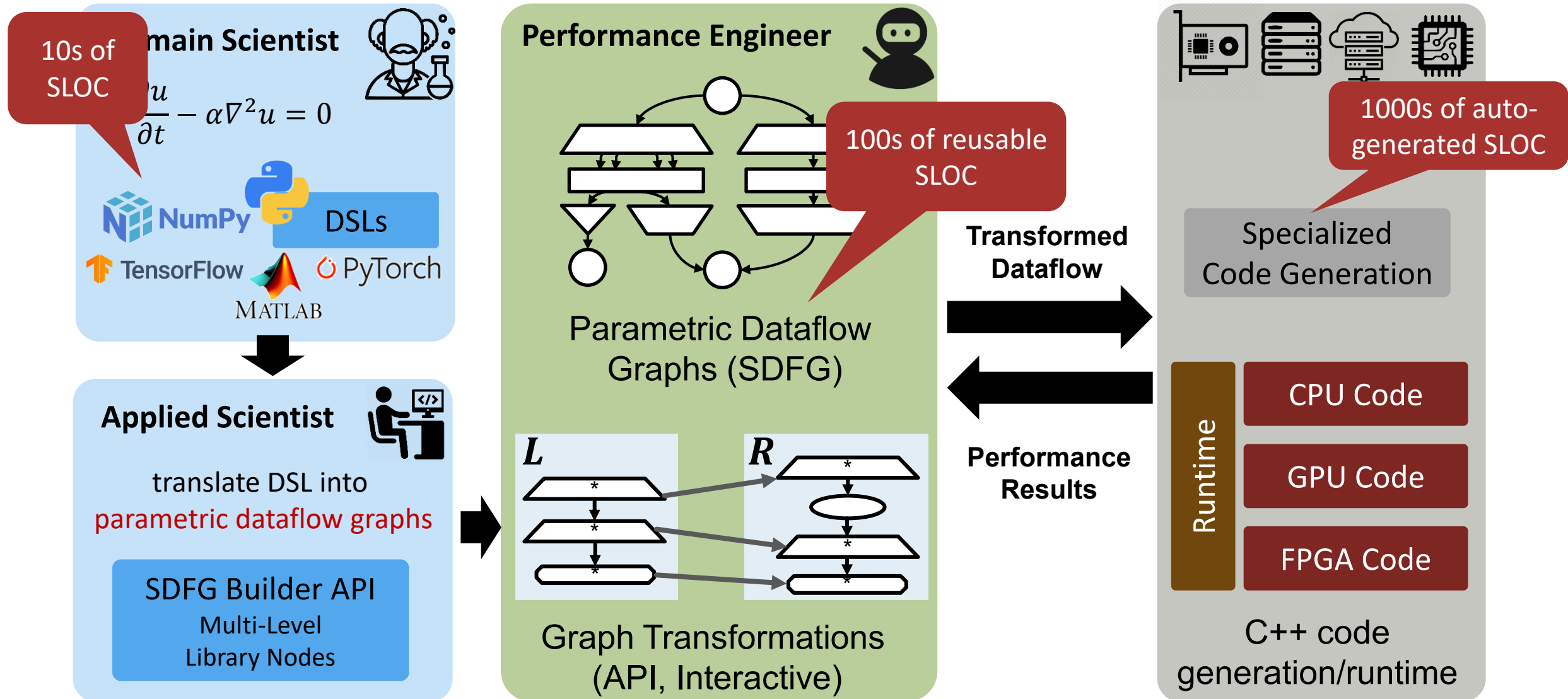
Imagine being a Fortran Compiler (same for Python if it compiles)



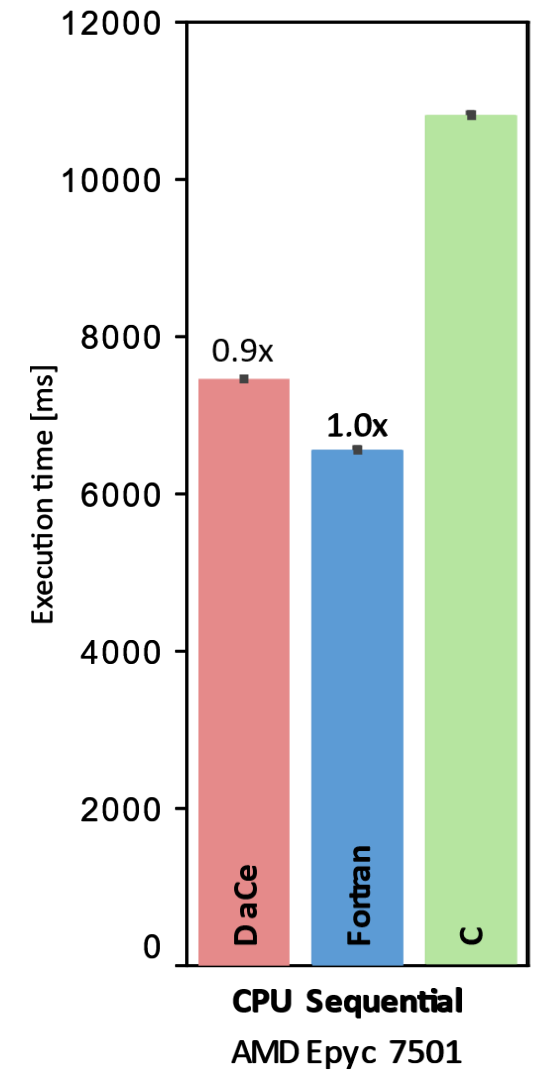
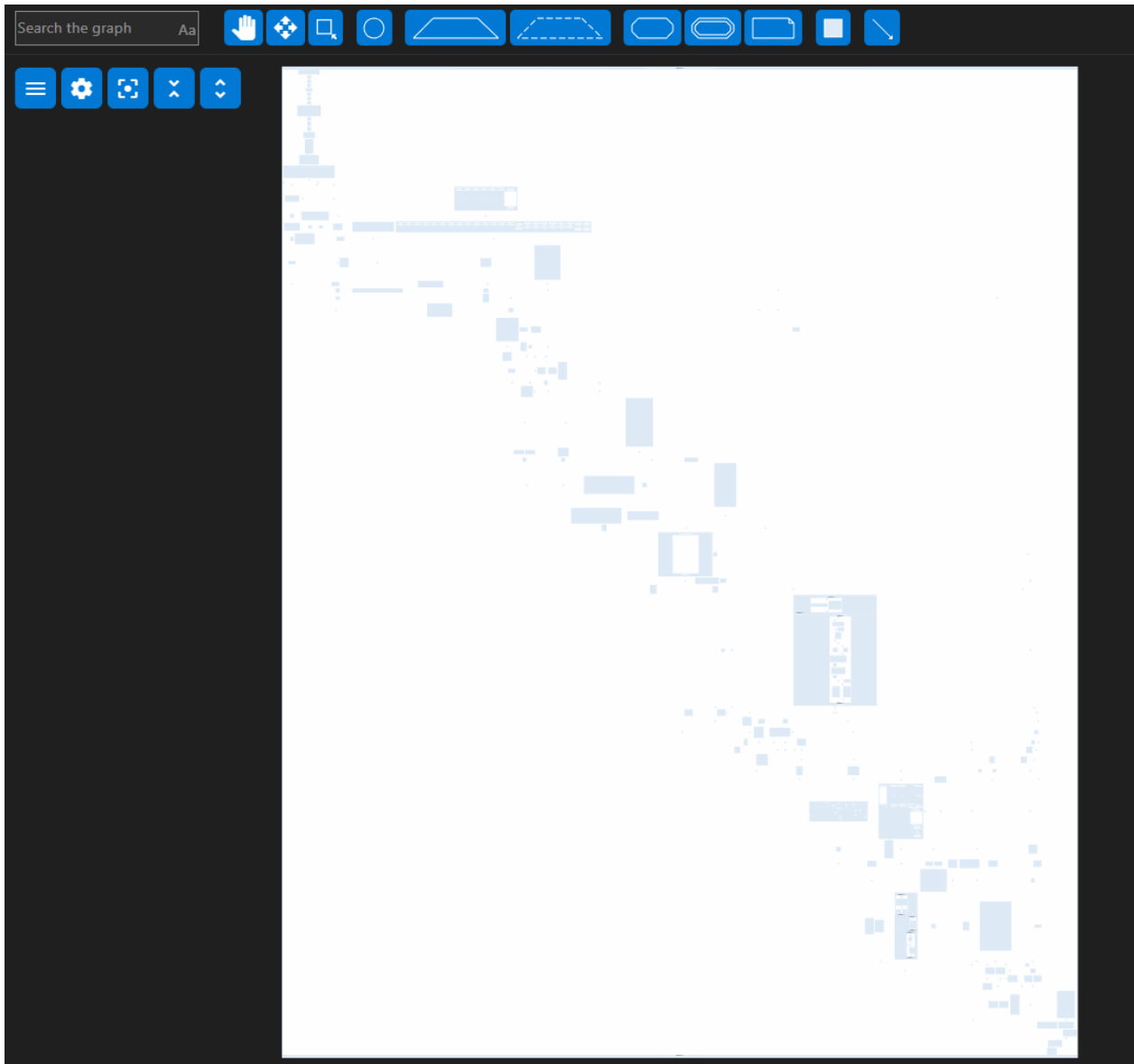
Team up with
Performance engineers!



Performance Metaprogramming for Performance Portability



SDFG view of CLOUDSC – investigate dataflow



Transformations in DaCe – Performance Metaprogramming!

Expose parallelism

- Data management transformations:
 - Changing data container lifetime **1**
 - Versioning data containers **2**
- Loop Parallelization **2**

```

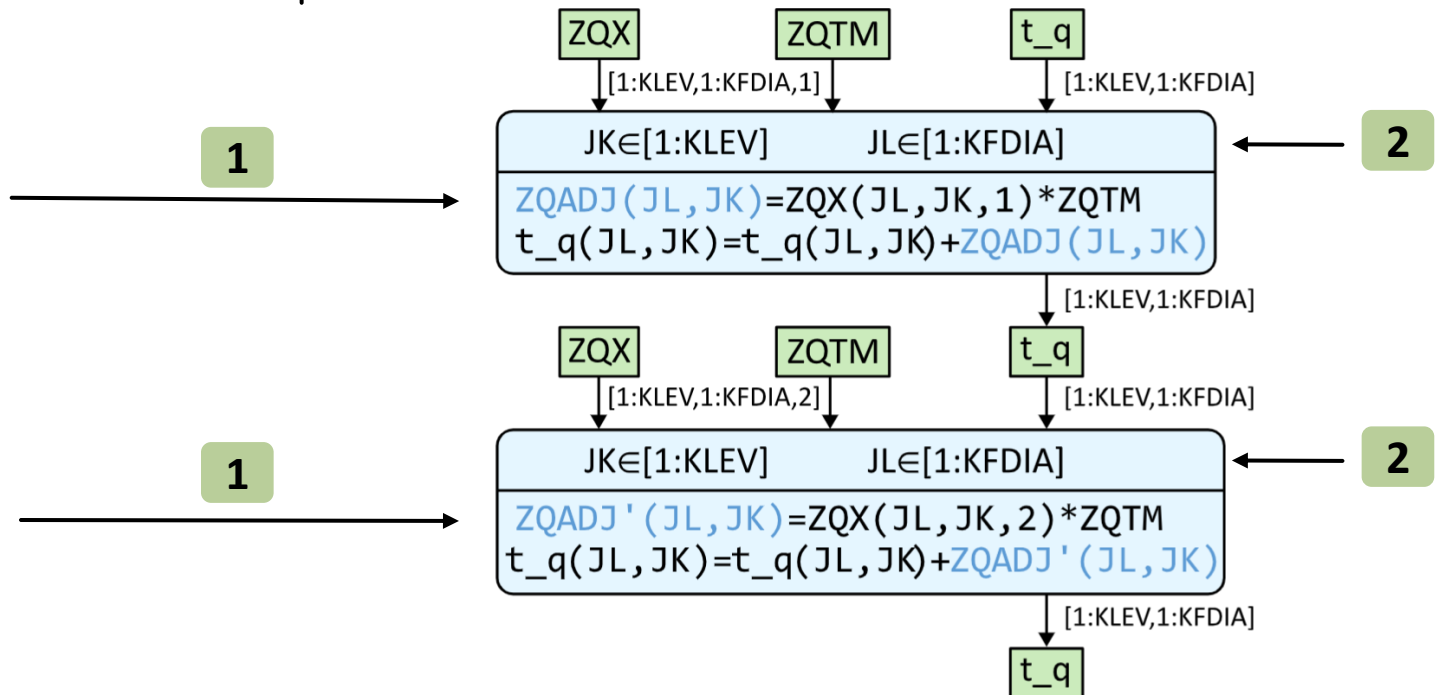
do JK=1,KLEV
  do JL=1,KFDIA
    ZQADJ=ZQX(JL,JK,1)*ZQTM
    t_q(JL,JK)=t_q(JL,JK)+ZQADJ
  enddo
enddo
  
```

```

do JK=1,KLEV
  do JL=1,KFDIA
    ZQADJ=ZQX(JL,JK,2)*ZQTM
    t_q(JL,JK)=t_q(JL,JK)+ZQADJ
  enddo
enddo
  
```

Improve performance

- Specializing numerical values
- Changing the data layout



Performance Metaprogramming Tooling!

```

void Loop_fun(double *ZFALLSINK, double *ZQXN, double *ZRDTGDP,
double *ZPFPLSX, int NPROMA, int KLON, int KLEV, int i, int k) {
  for (int j = 0; j < NPROMA; j++)
    ZPFPLSX[KLON*k+KLON*(KLEV+1)*i+j] =
      ZFALLSINK[KLON*i+j] * ZQXN[KLON*i+j] * ZRDTGDP[j];
}

void fun(double *ZFALLSINK, double *ZQXN, double *ZRDTGDP, double *ZPFPLSX,
int NCLV, int NPROMA, int KLON, int KLEV, int i, int k) {
  //...
  Loop_fun(ZFALLSINK, ZQXN, ZRDTGDP, ZPFPLSX, NPROMA, KLON, KLEV, i, k);
  //...
}

```



GPU Kernel Extraction Transformation

```

void fun_gpu(double *ZFALLSINK, double *ZQXN, double *ZRDTGDP,
double *ZPFPLSX, int NCLV, int NPROMA, int KLON, int KLEV, int i, int k) {
  //...
  double *gZQXN, *gZRDTGDP, *gZFALLSINK, *gZPFPLSX;
  cudaMalloc((void*)&gZQXN, KLON * NCLV * sizeof(double));
  cudaMalloc((void*)&gZRDTGDP, KLON * sizeof(double));
  cudaMalloc((void*)&gZFALLSINK, KLON * NCLV * sizeof(double));
  cudaMalloc((void*)&gZPFPLSX, KLON * NCLV * (KLEV + 1) * sizeof(double));
  cudaMemcpyAsync(gZQXN, ZQXN, KLON * NCLV * sizeof(double),
cudaMemcpyHostToDevice);
  cudaMemcpyAsync(gZRDTGDP, ZRDTGDP, KLON * sizeof(double),
cudaMemcpyHostToDevice);
  cudaMemcpyAsync(gZFALLSINK, ZFALLSINK, KLON * NCLV * sizeof(double),
cudaMemcpyHostToDevice);
  void *args[] = {&gZFALLSINK, &gZQXN, &gZRDTGDP, &gZPFPLSX, &NPROMA,
&KLON, &KLEV, &i, &k};
  cudaLaunchKernel((void*)Loop_fun, dim3(32, 1, 1), dim3(32, 1, 1), args, 0, 0);
  cudaMemcpyAsync(ZPFPLSX, gZPFPLSX, KLON * NCLV * (KLEV + 1) * sizeof(double),
cudaMemcpyDeviceToHost);
  // CUDA free (omitted for brevity)
  //...
}

```



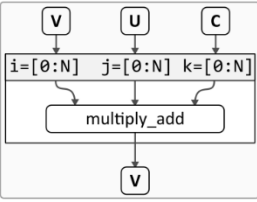
Isolate side effects

```

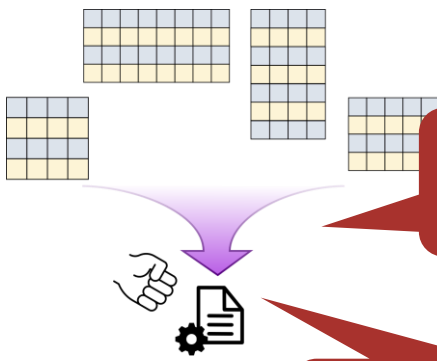
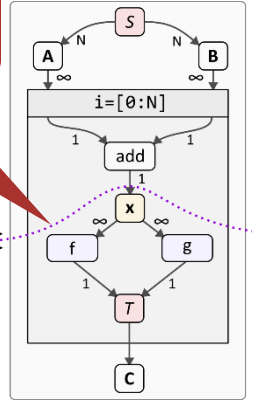
DATA_TTYPE t0, t1, t2, t3, t4, t5, t6, t7, t8;
DATA_TTYPE t9, t10, t11, t12, t13, t14, t15;

for (i=0; i<PB_M; i++) {
  y0 = SCALAR_VAL(0.0);
  y1 = SCALAR_VAL(0.0);
  y2 = SCALAR_VAL(0.0);
  y3 = SCALAR_VAL(0.0);
  y4 = SCALAR_VAL(0.0);
  y5 = SCALAR_VAL(0.0);
  y6 = SCALAR_VAL(0.0);
  y7 = SCALAR_VAL(0.0);
  y8 = SCALAR_VAL(0.0);
  y9 = SCALAR_VAL(0.0);
  y10 = SCALAR_VAL(0.0);
  y11 = SCALAR_VAL(0.0);
  y12 = SCALAR_VAL(0.0);
  y13 = SCALAR_VAL(0.0);
  y14 = SCALAR_VAL(0.0);
  y15 = SCALAR_VAL(0.0);
  y16 = SCALAR_VAL(0.0);
  y17 = SCALAR_VAL(0.0);
  y18 = SCALAR_VAL(0.0);
  y19 = SCALAR_VAL(0.0);
  y20 = SCALAR_VAL(0.0);
  y21 = SCALAR_VAL(0.0);
  y22 = SCALAR_VAL(0.0);
  y23 = SCALAR_VAL(0.0);
  y24 = SCALAR_VAL(0.0);
  y25 = SCALAR_VAL(0.0);
  y26 = SCALAR_VAL(0.0);
  y27 = SCALAR_VAL(0.0);
  y28 = SCALAR_VAL(0.0);
  y29 = SCALAR_VAL(0.0);
  y30 = SCALAR_VAL(0.0);
  y31 = SCALAR_VAL(0.0);
  y32 = SCALAR_VAL(0.0);
  y33 = SCALAR_VAL(0.0);
  y34 = SCALAR_VAL(0.0);
  y35 = SCALAR_VAL(0.0);
  y36 = SCALAR_VAL(0.0);
  y37 = SCALAR_VAL(0.0);
  y38 = SCALAR_VAL(0.0);
  y39 = SCALAR_VAL(0.0);
  y40 = SCALAR_VAL(0.0);
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  y42 = SCALAR_VAL(0.0);
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  y44 = SCALAR_VAL(0.0);
  y45 = SCALAR_VAL(0.0);
  y46 = SCALAR_VAL(0.0);
  y47 = SCALAR_VAL(0.0);
  y48 = SCALAR_VAL(0.0);
  y49 = SCALAR_VAL(0.0);
  y50 = SCALAR_VAL(0.0);
  y51 = SCALAR_VAL(0.0);
  y52 = SCALAR_VAL(0.0);
  y53 = SCALAR_VAL(0.0);
  y54 = SCALAR_VAL(0.0);
  y55 = SCALAR_VAL(0.0);
  y56 = SCALAR_VAL(0.0);
  y57 = SCALAR_VAL(0.0);
  y58 = SCALAR_VAL(0.0);
  y59 = SCALAR_VAL(0.0);
  y60 = SCALAR_VAL(0.0);
  y61 = SCALAR_VAL(0.0);
  y62 = SCALAR_VAL(0.0);
  y63 = SCALAR_VAL(0.0);
  y64 = SCALAR_VAL(0.0);
  y65 = SCALAR_VAL(0.0);
  y66 = SCALAR_VAL(0.0);
  y67 = SCALAR_VAL(0.0);
  y68 = SCALAR_VAL(0.0);
  y69 = SCALAR_VAL(0.0);
  y70 = SCALAR_VAL(0.0);
  y71 = SCALAR_VAL(0.0);
  y72 = SCALAR_VAL(0.0);
  y73 = SCALAR_VAL(0.0);
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  y75 = SCALAR_VAL(0.0);
  y76 = SCALAR_VAL(0.0);
  y77 = SCALAR_VAL(0.0);
  y78 = SCALAR_VAL(0.0);
  y79 = SCALAR_VAL(0.0);
  y80 = SCALAR_VAL(0.0);
  y81 = SCALAR_VAL(0.0);
  y82 = SCALAR_VAL(0.0);
  y83 = SCALAR_VAL(0.0);
  y84 = SCALAR_VAL(0.0);
  y85 = SCALAR_VAL(0.0);
  y86 = SCALAR_VAL(0.0);
  y87 = SCALAR_VAL(0.0);
  y88 = SCALAR_VAL(0.0);
  y89 = SCALAR_VAL(0.0);
  y90 = SCALAR_VAL(0.0);
  y91 = SCALAR_VAL(0.0);
  y92 = SCALAR_VAL(0.0);
  y93 = SCALAR_VAL(0.0);
  y94 = SCALAR_VAL(0.0);
  y95 = SCALAR_VAL(0.0);
  y96 = SCALAR_VAL(0.0);
  y97 = SCALAR_VAL(0.0);
  y98 = SCALAR_VAL(0.0);
  y99 = SCALAR_VAL(0.0);
}

```



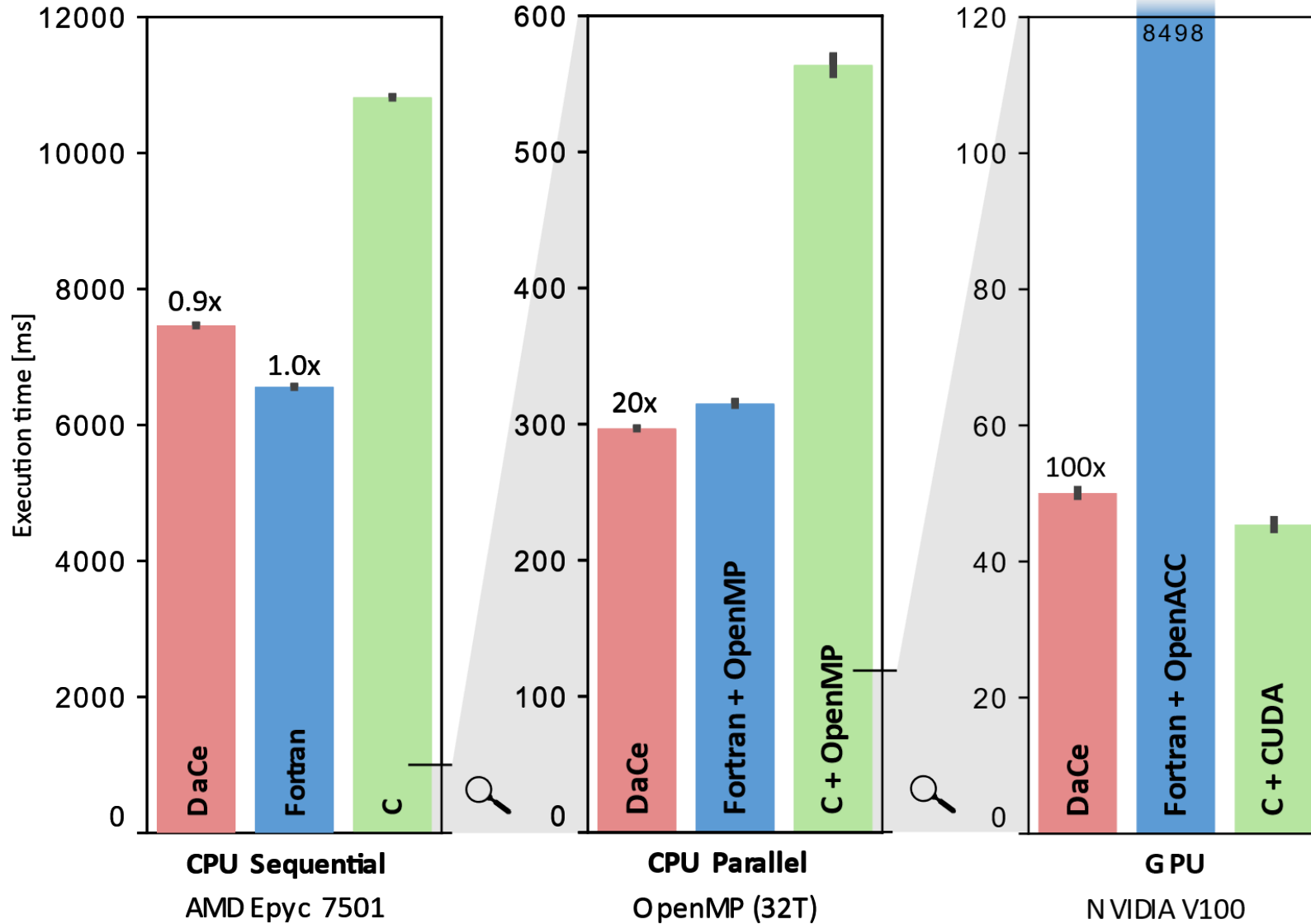
Grow test cases to reduce input size



Differential gray-box fuzzing

100s of tests per second!

Performance portability – all from the original, unchanged CLOUDSC code!



Conclusions

DSLs on the rise! ?

- Lots of DSLs for performance portability
- I somewhat see those as an attempt to uplevel performance
- BLAS, LINPACK, LAPACK, etc.

The core of many scientific problems is manipulation

- The oldest DSL of all: Fortran = Formula Translator
 - Invented by Turing Awardee John Backus in 1957 (at IBM)
 - At the time, people were skeptical that it would beat
 - Gave rise to the first optimizing compiler!

REVIEW ARTICLES

Disentangling Hype from Practicality: On Realistically Achieving Quantum Advantage

By Torsten Hoefer, Thomas Häner, Matthias Troyer
 Communications of the ACM, May 2023, Vol. 66 No. 5, Pages 82-87
 10.1145/3571725

Comments

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Credit: Andrij Borys Associates, Shutterstock

Operating on fundamentally different principles than conventional computers, quantum computers promise to solve a variety of important problems that seemed forever intractable on classical computers. Leveraging the quantum foundations of nature, the time to solve certain problems on quantum computers grows more slowly with the size of the problem than on classical computers—this is called *quantum speedup*. Going beyond quantum supremacy,² which was the demonstration of a quantum computer outperforming a classical one for an artificial problem, an important question is finding meaningful applications (of academic or commercial interest) that can realistically be solved faster on a quantum computer than on a classical one. We call this a practical quantum advantage, or *quantum practicality* for short.

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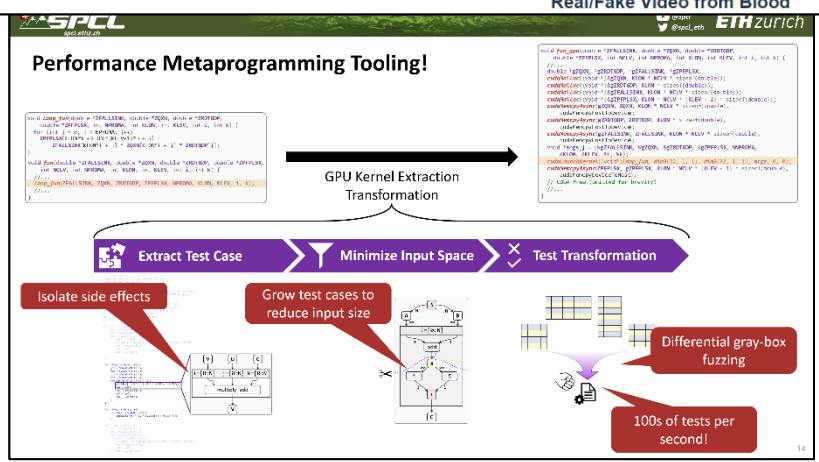
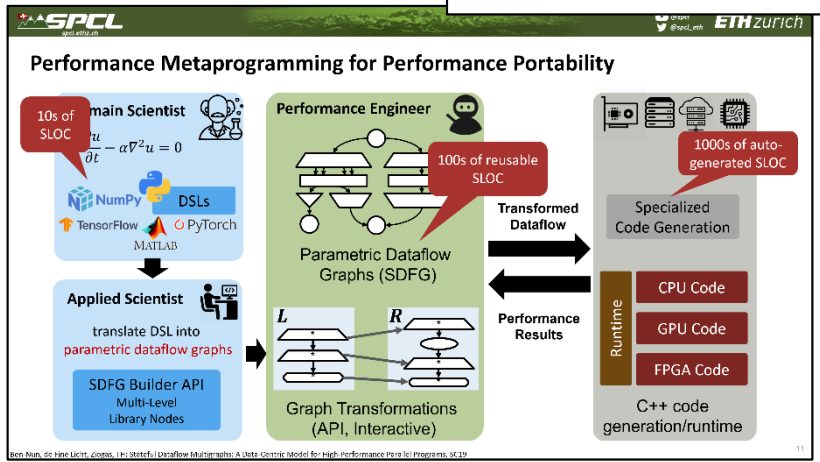
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Deepfake Detector Can Spot Real/Fake Video from Blood

More of SPCL's research:

- youtube.com/@spcl **175+ Talks**
- twitter.com/spcl_eth **1.2K+ Followers**
- github.com/spcl **2K+ Stars**

... or spcl.ethz.ch



- Fortran / NumPy works (somewhat!)
 - Full automation of performance portability does not work!
 - “Opening up the compiler” via **performance metaprogramming!**
 - Achieving hand-tuned performance for some codes!
- Looking into metaprogramming tooling / theory for optimization!