# Assessing Representativeness of Kernels using Descriptive Statistics

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National Center for Atmospheric Research

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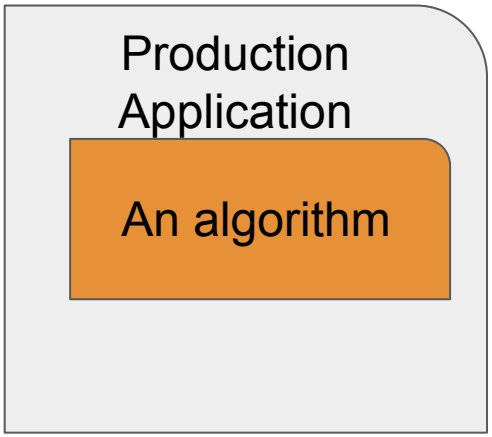
# Contents



- KGen: an automated kernel generation tool
- KGen representativeness extension
- Case studies
  - Two cases from a large Fortran applications
  - One case from using a LAPACK routine

# Overview





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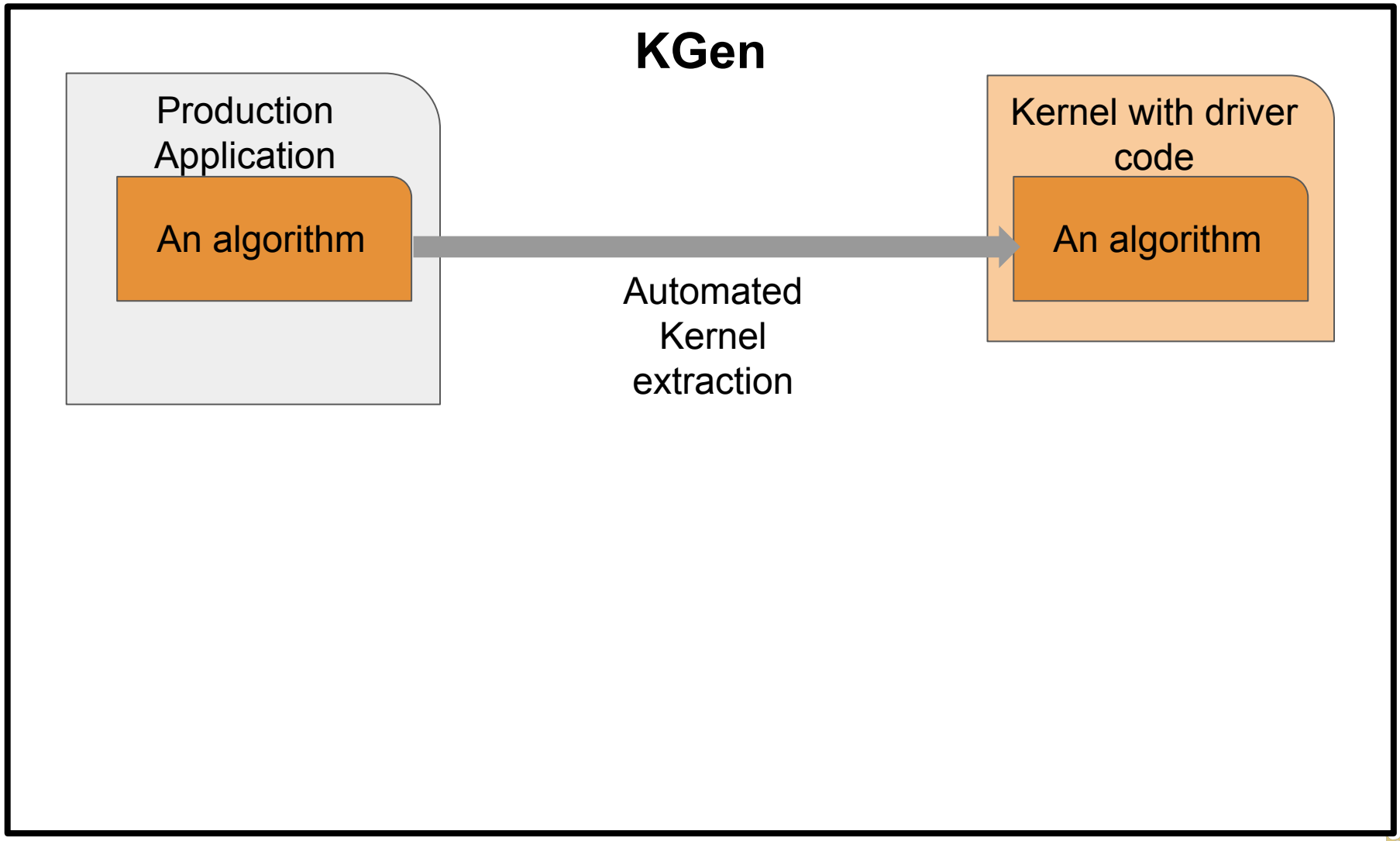
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Production Application
An algorithm
Automated Kernel extraction
Kernel with driver code
An algorithm

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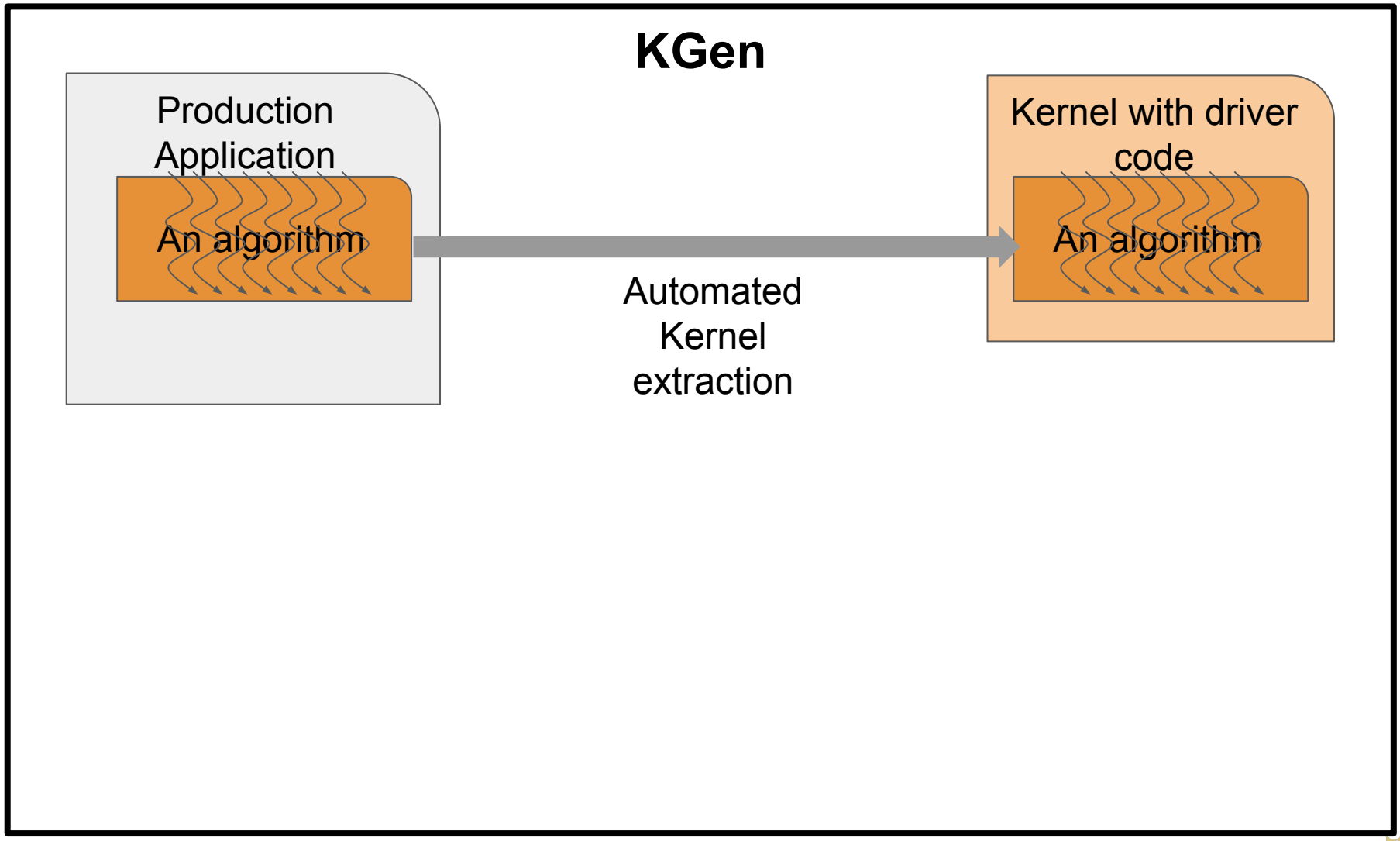
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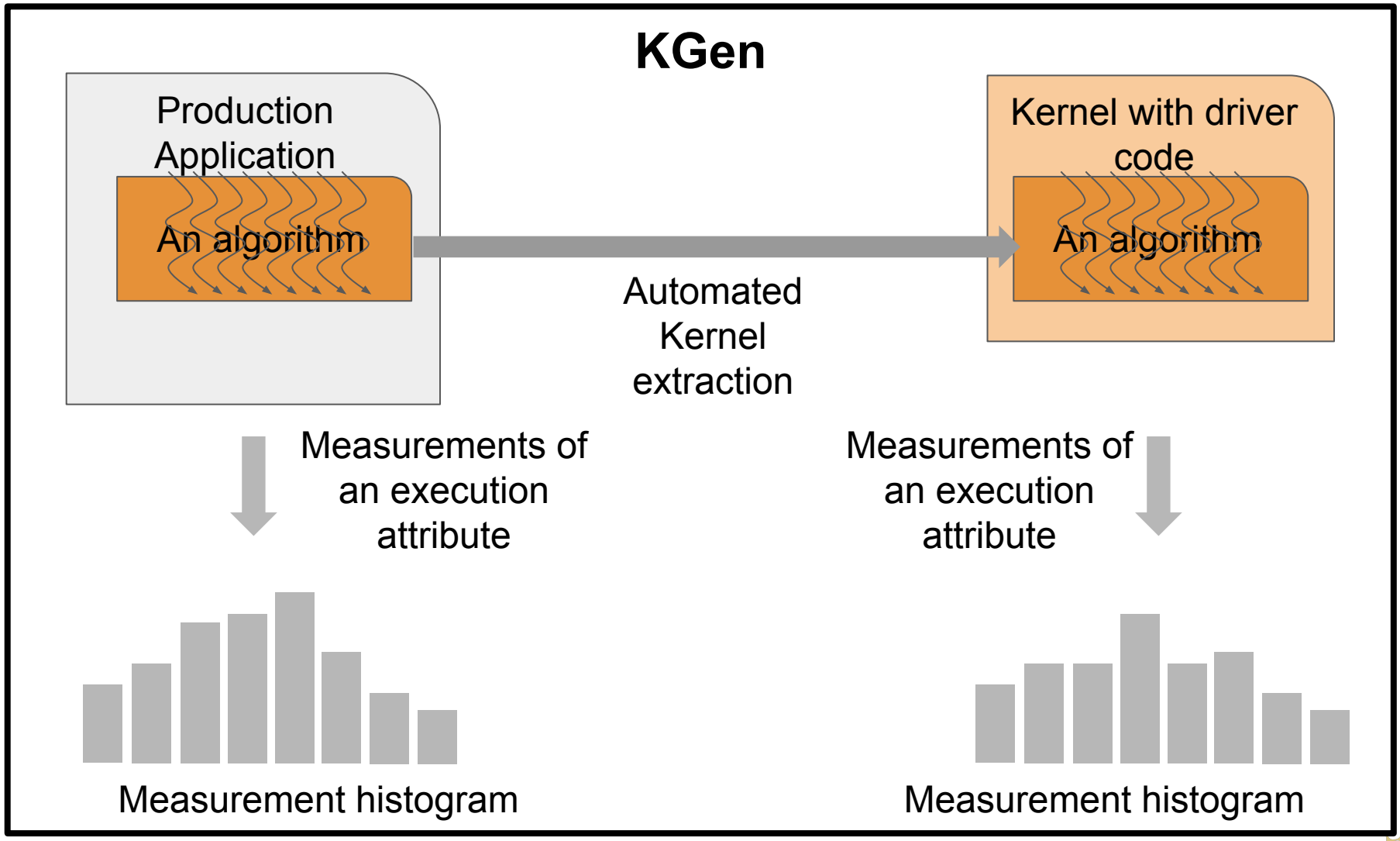
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Measurement histogram
Measurement histogram

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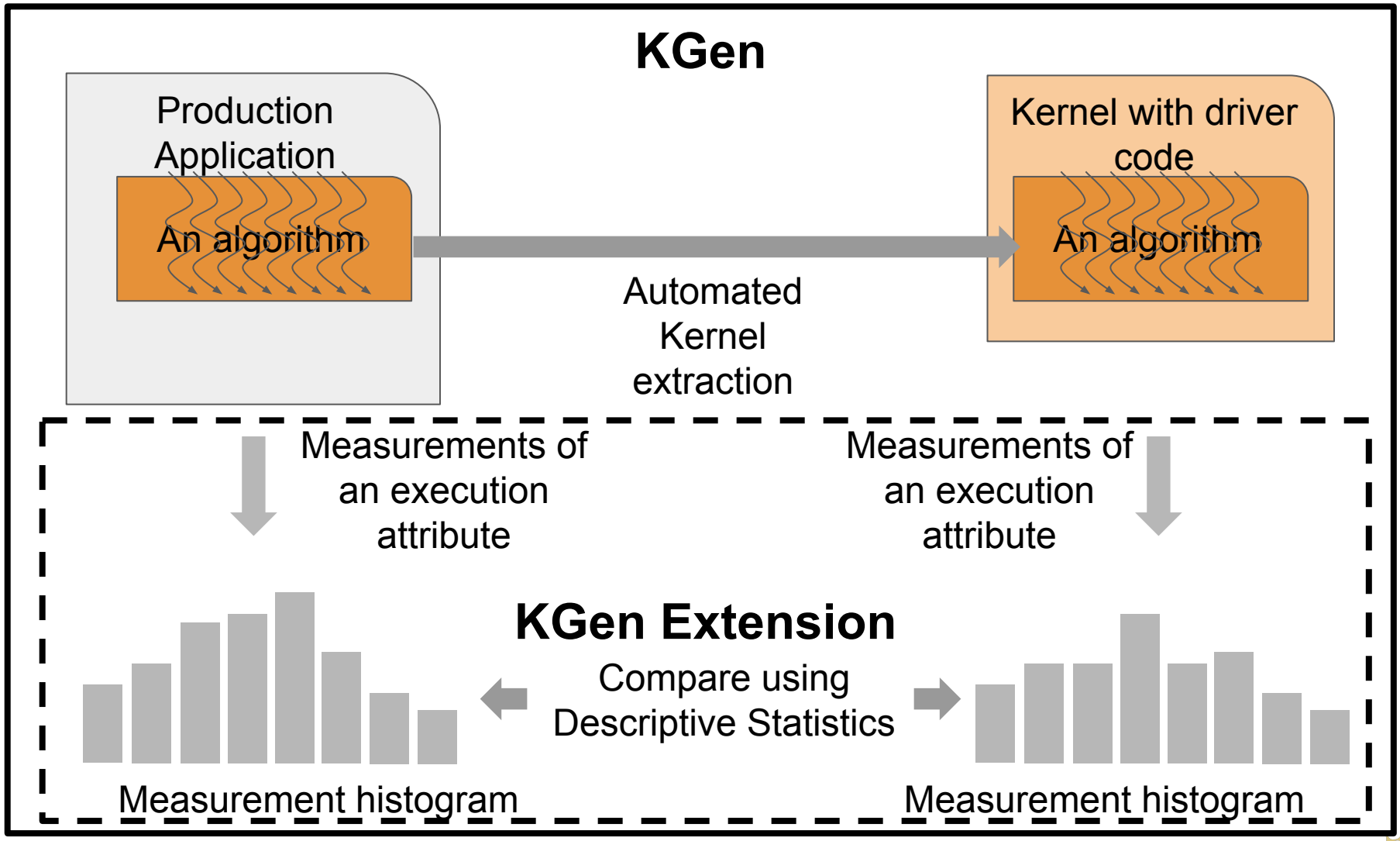
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KGen Extension
Compare using Descriptive Statistics
Measurement histogram
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# KGen Introduction

# Manual extraction vs. automated extraction



**SUBROUTINE** micro_mg_tend(microp_uniform, pcols, pver, ncol, top_lev, deltatin, tn, qn, qc, qi, nc, ni, p, pdel, cldn, liqcldf, relvar, accre_enhan, icecldf, rate1ord_cw2pr_st, naai, npccnin, rndst, nacon, tlat, qvlat, qctend, qitend, nctend, nitend, effc, effc_fn, effi, prect, preci, nevapr, evapsnow, am_evp_st, prain, prodsnow, cmeout, deffi, pgamrad, lamcrad, qsout, dsout, rflx, sflx, qrout, reff_rain, reff_snow, qcsevap, qisevap, qvres, cmeiout, vtrmc, vtrmi, qcsedten, qisedten, prao, prco, mnuccco, mnuccto, msacwio, psacwso, bergso, bergo, melto, homoo, qcreso, prcio, praio, qireso, mnuccro, pracso, meltsdt, frzrdt, mnuccdo, nrout, nsout, refl, arefl, areflz, frefl, csrfl, acsrfl, fcsrfl, rercld, ncai, ncal, qrout2, qsout2, nrout2, nsout2, drout2, dsout2, freqs, freqr, nfice, do_cldice, tnd_qsnow, tnd_nsnow, re_ice, errstring)

- 1921 lines without comment and blank lines
- 11 functions called directly or indirectly

**END SUBROUTINE** micro_mg_tend

# Why we needed a kernel generation tool?



Community Earth System Model (CESM)

- > 1.5 mil. LOC
- > 400 registered developers
- > 5100 registered users

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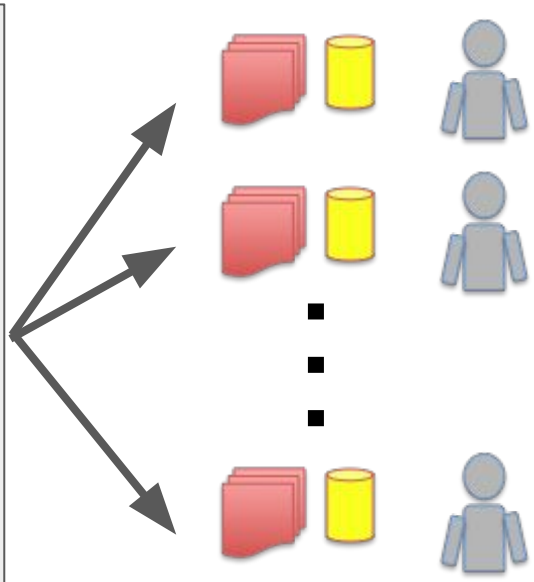

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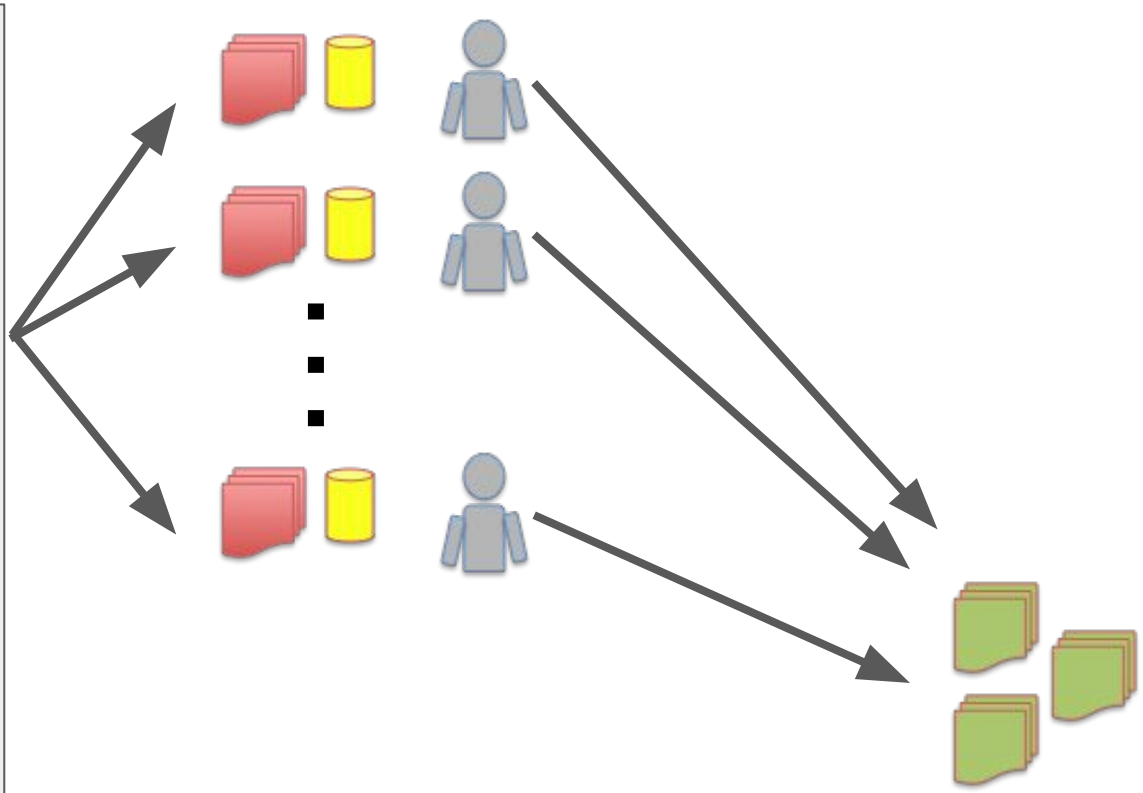

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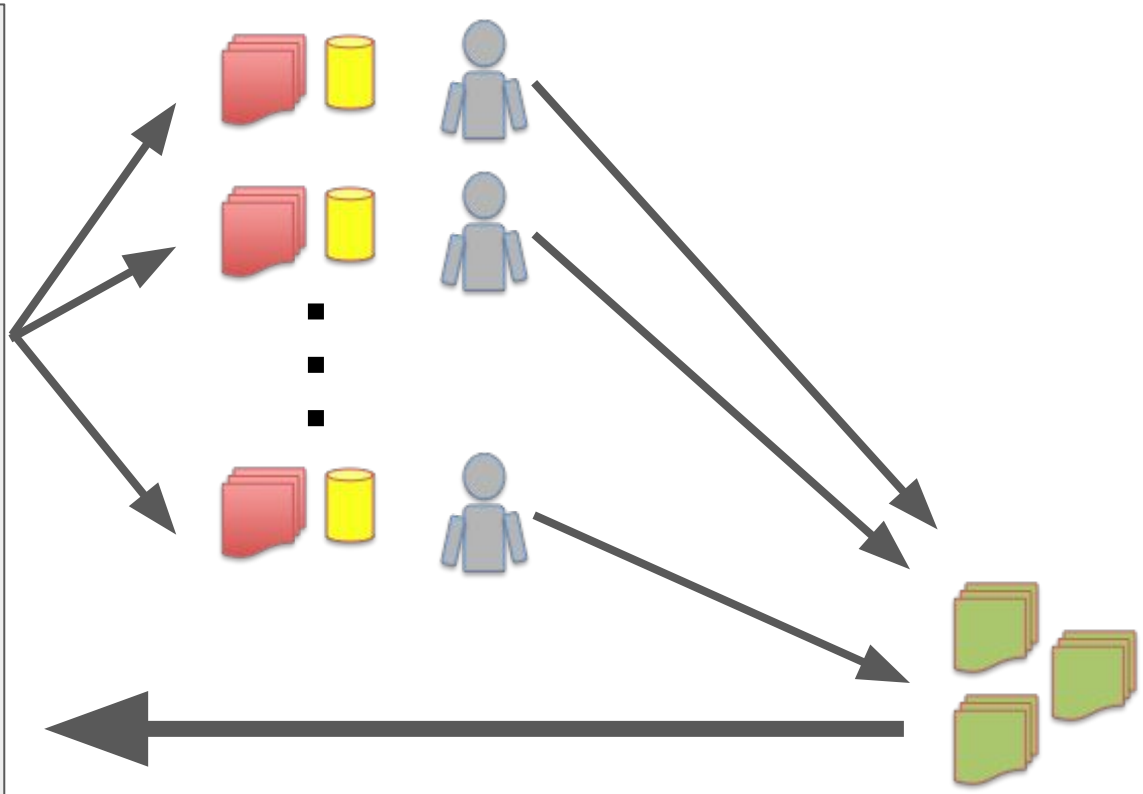

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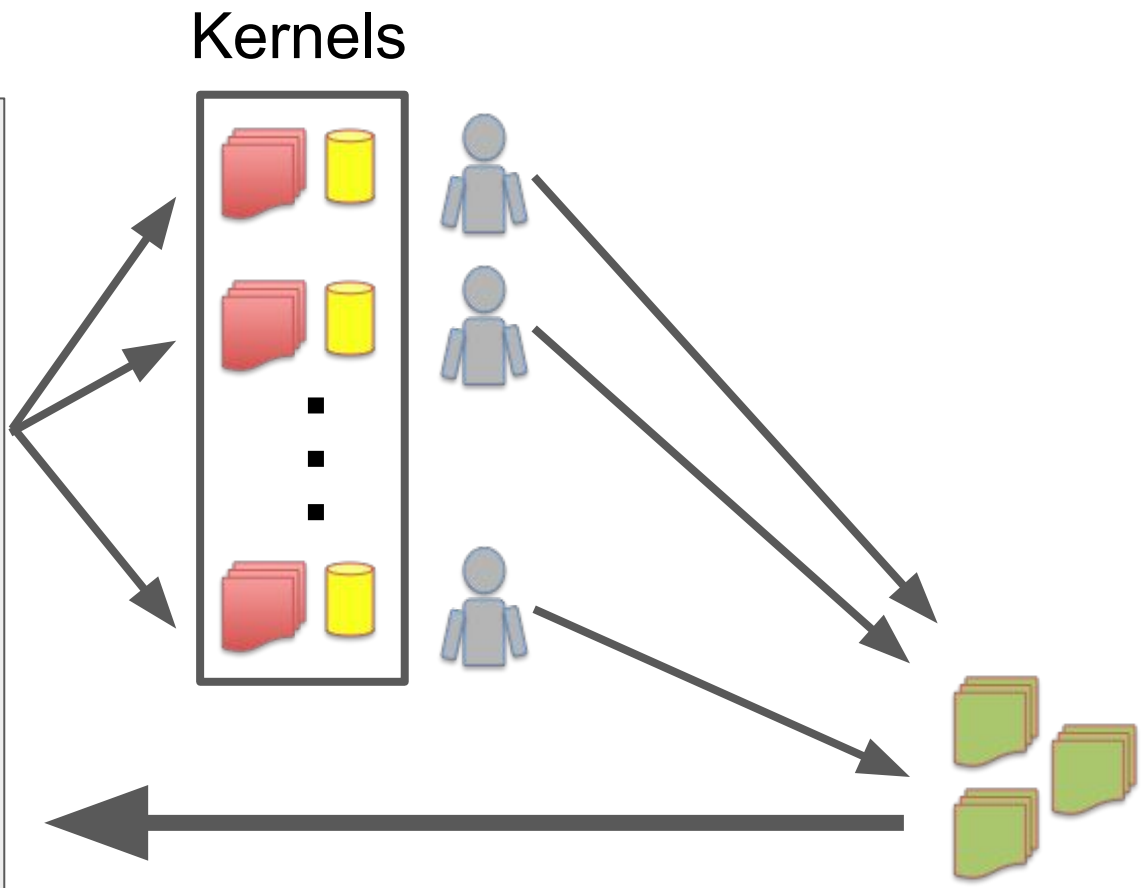
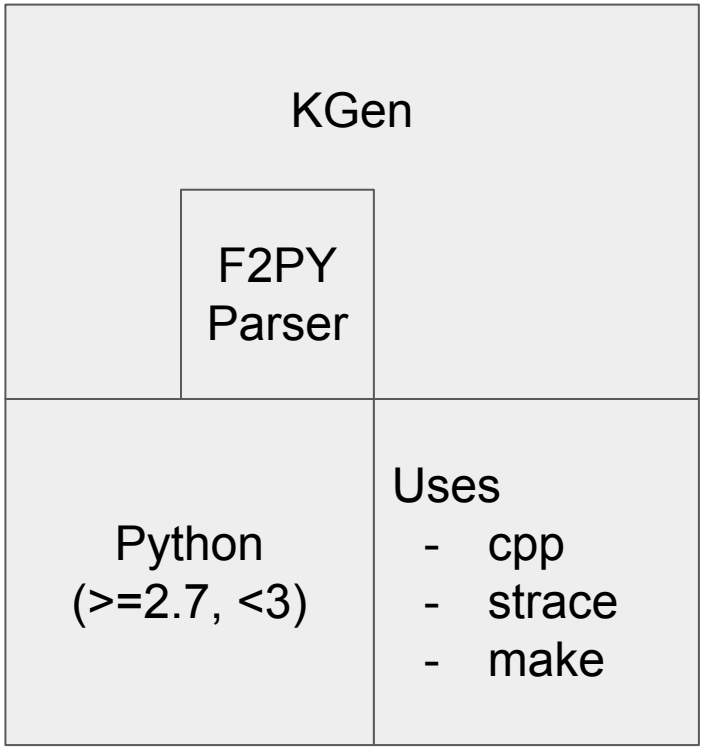


- KGen **extracts** a region of source-code as a stand-alone software out of a large Fortran software application
- In addition, it generates **input & output data** for execution and verification of the generated kernel
- **Correctness check and timing measurement** are included in the generated kernel

KGen github: https://github.com/NCAR/KGen

# KGen: self-contained static analysis tool



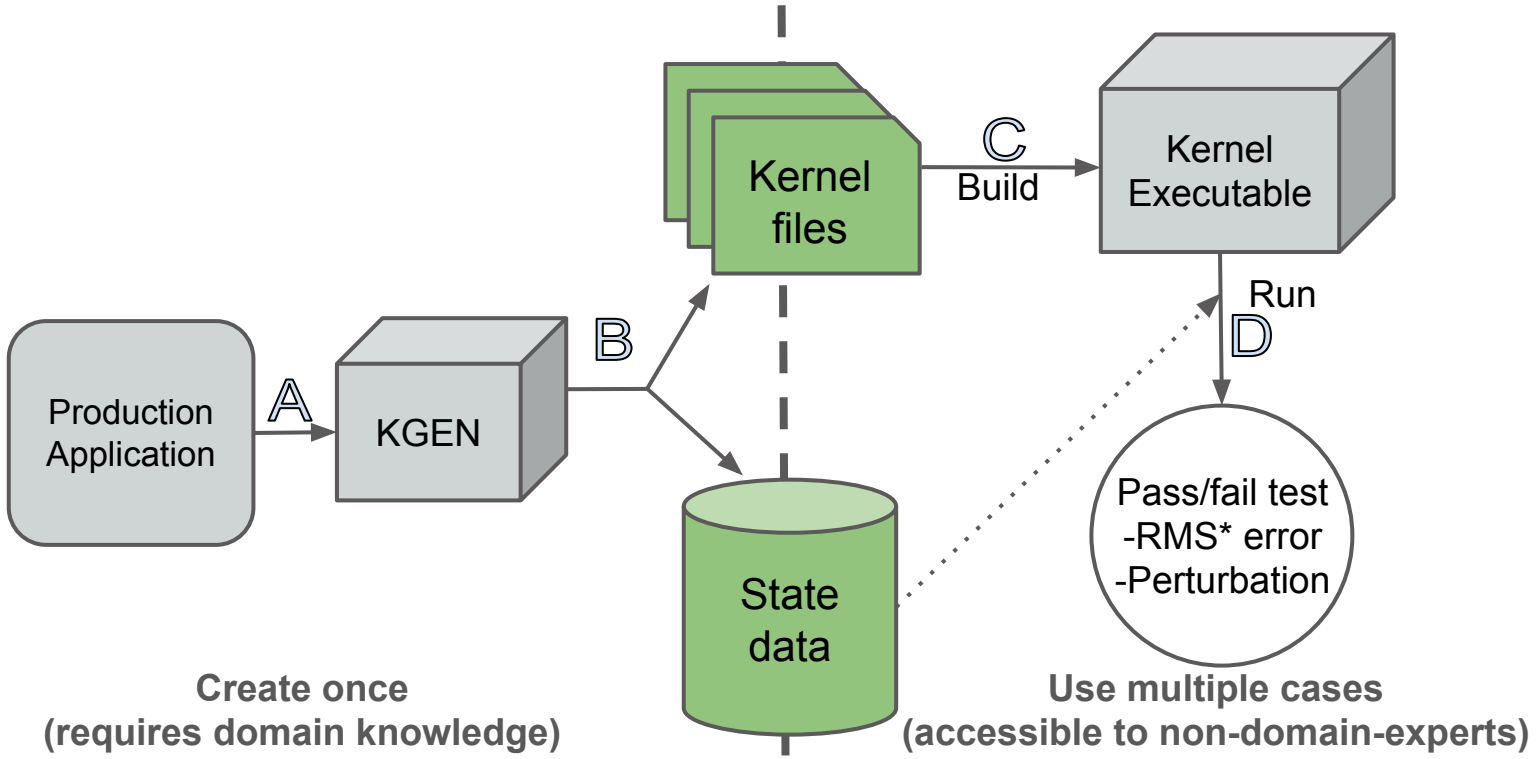



- Written in Python
  - No external compiler or analysis framework
  - Performs static analysis on ASTs
- Uses F2PY* Fortran Parser
  - Integrated and extended in KGen
  - Produces ASTs for analysis
- Uses three Linux utilities
  - cpp: preprocessing
  - strace: collect macros and include paths
  - make: executes KGen-generated kernel

F2PY*: Fortran to Python interface generator(https://github.com/pearu/f2py)

# KGen: Create a kernel once, use many times






A) User specifies a kernel region and also provides clean/build/run command(s) for application

B) KGen generates a stand-alone kernel files and state data files

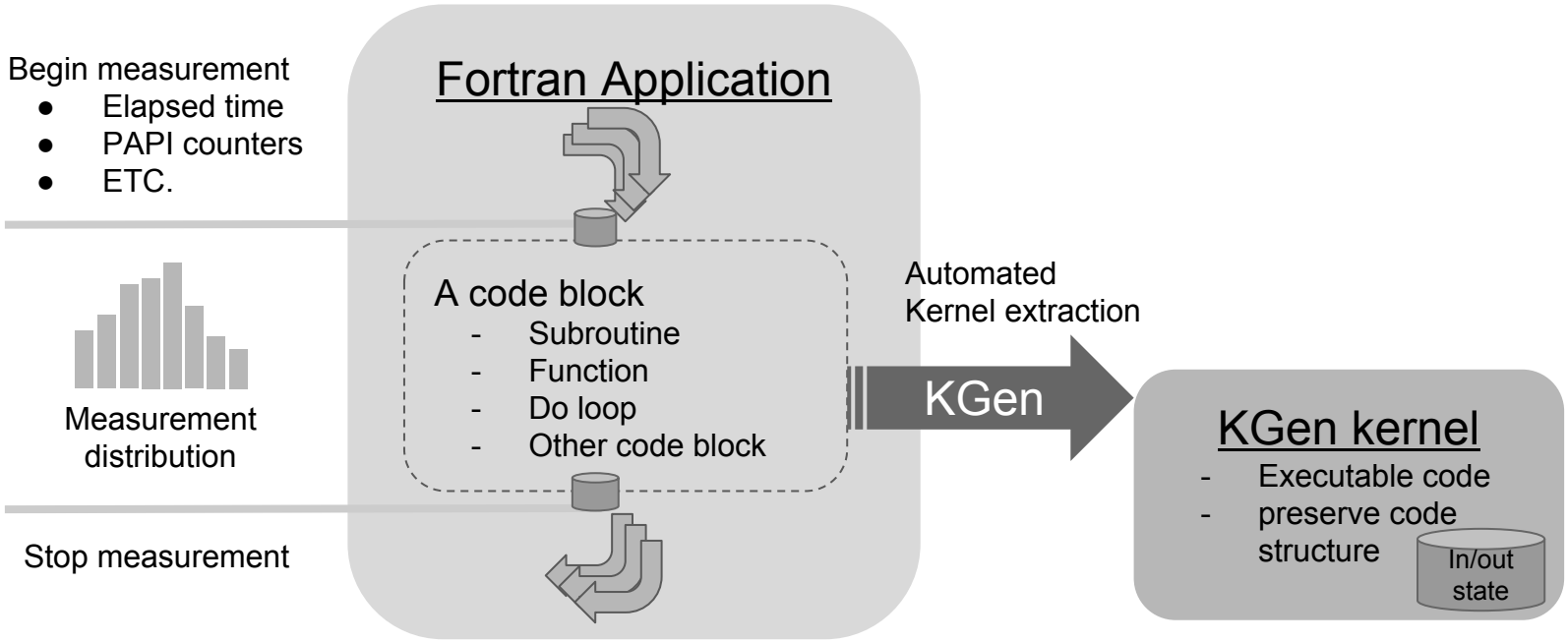
C) User builds kernel through KGen-generated Makefile

D) User runs kernel with state data. KGen kernel includes verification and timing measurement

# KGen Representativeness Extension

# KGen Extension Concept

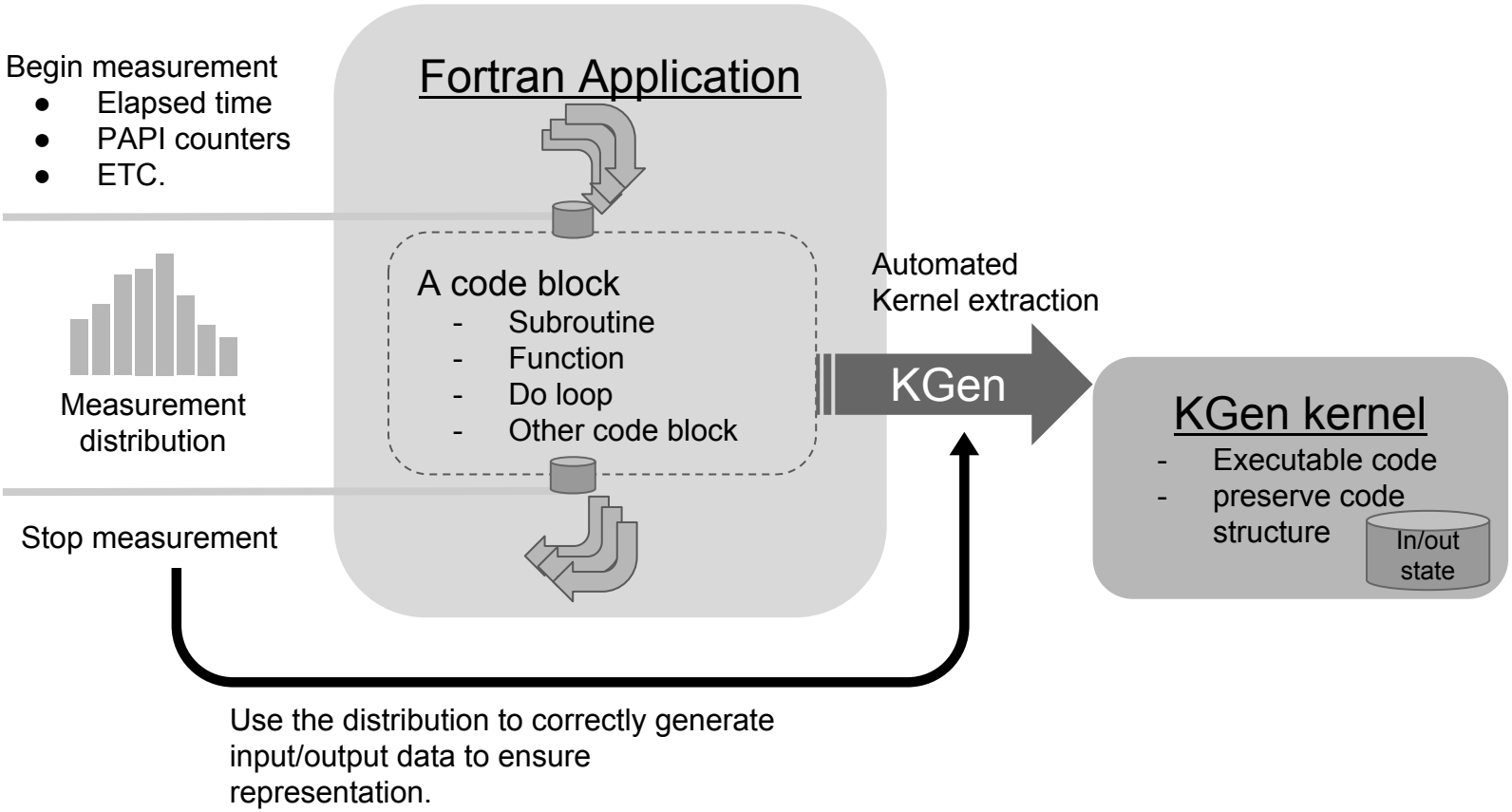





: Program Execution : Data Collection

# KGen Extension Concept



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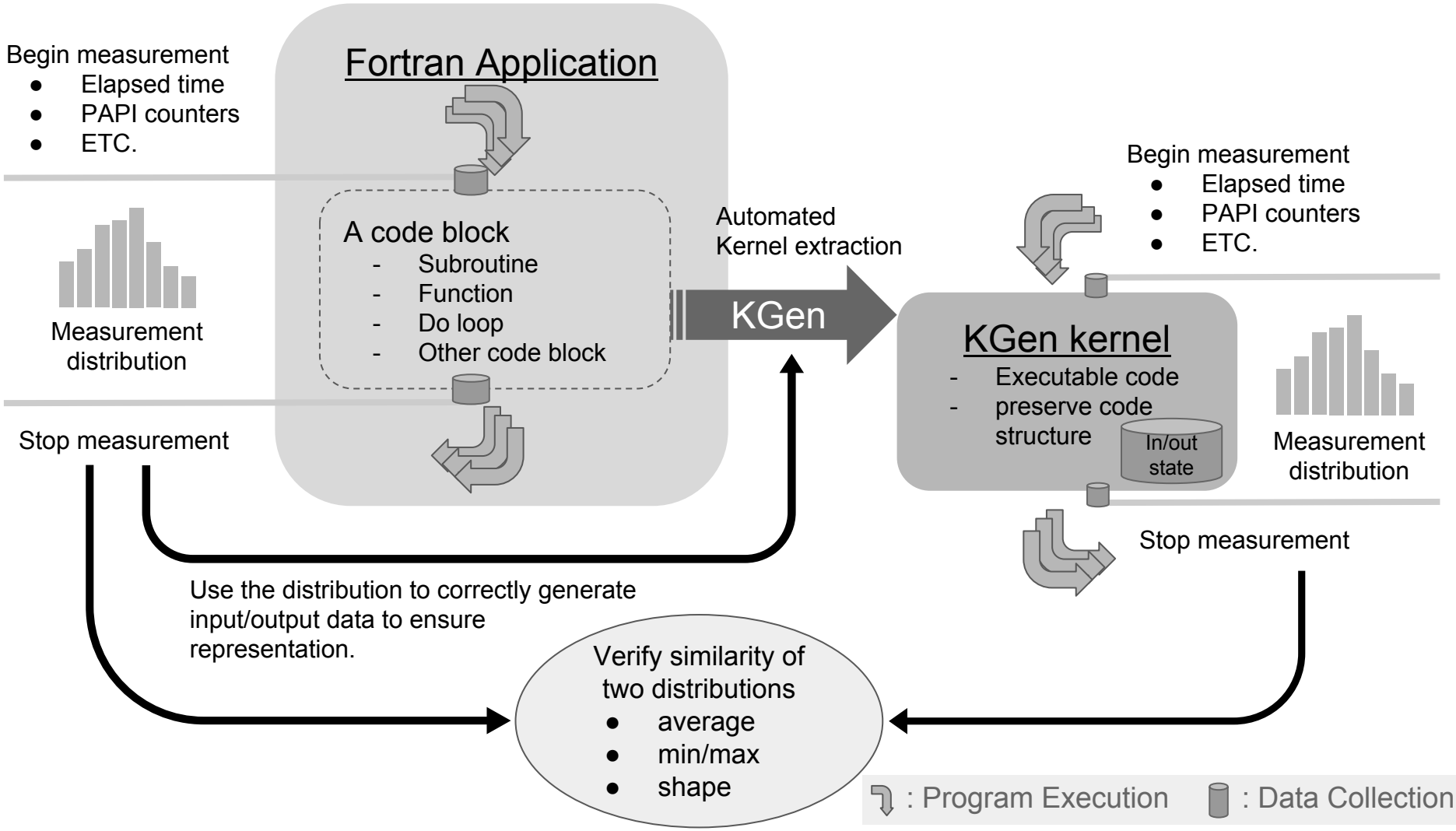
# KGen Extension Concept





# Content of measurements



- Invocation Triplets
  - MPI rank number
  - OpenMP thread ID
  - Invocation order
- Runtime attributes
  - Elapsed time
  - PAPI counter
  - Source code coverage
  - Will add more attributes in future

**Saved as 4-ary tuples of**

**( “MPI rank”, “OpenMP TID”, “Invocation order”, “runtime attribute”)**

# Measurement Method

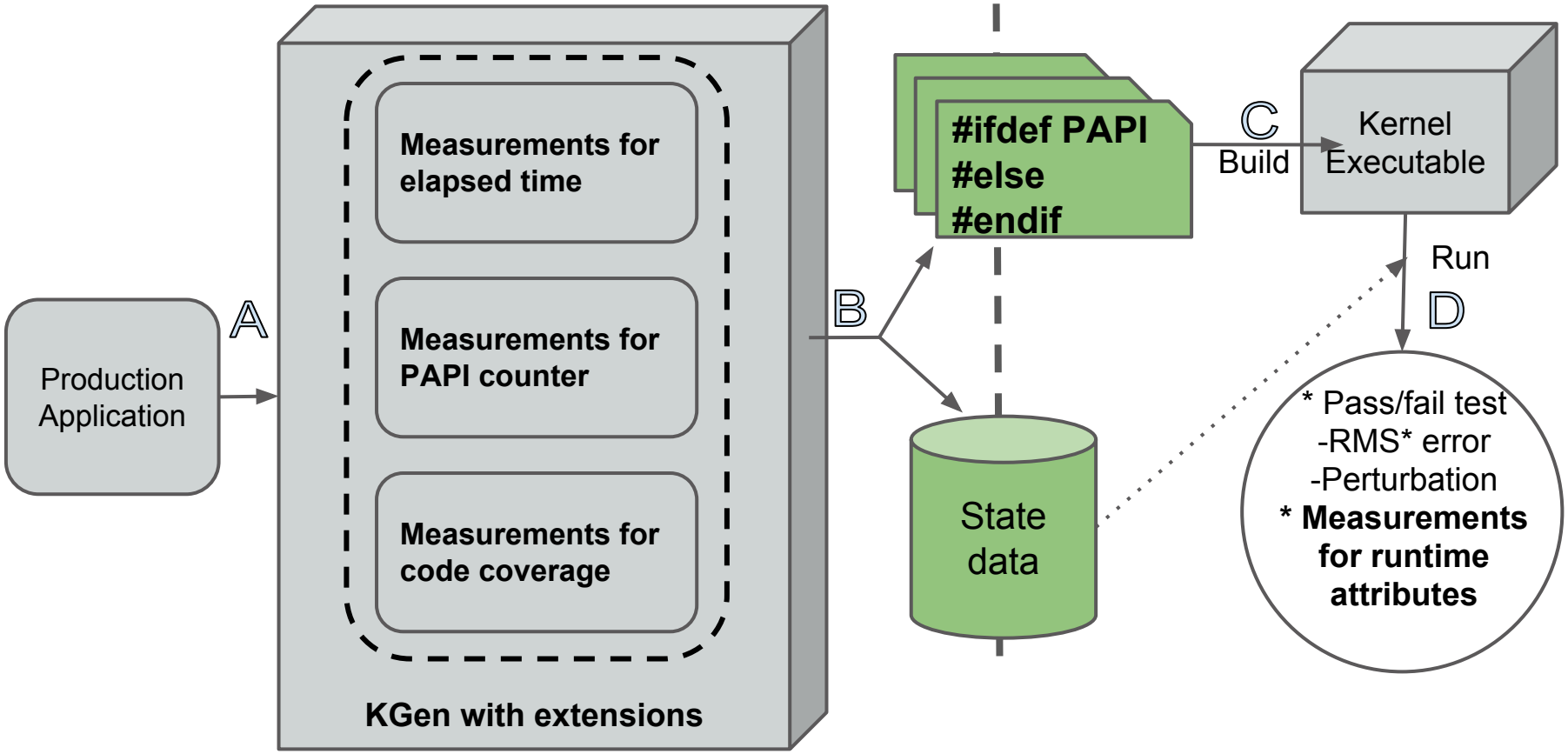


- Source code instrumentation for target application
  - Add collection code just before and after the kernel region
  - Maintains invocation triplets internally

- Additional code for generated kernel
  - Use macros to distinguish runtime attribute
  - Generated makefile helps to build with PAPI library
  - Source code coverage information is presented as annotated source code in each files.

# KGen with an extensions





# Descriptive statistics



- Types of descriptive statistics

| type | statistics |
|---|---|
| Central tendency | mean, median, mode |
| Variability | min, max, standard deviation, variance |
| Shape | kurtosis, skewness |

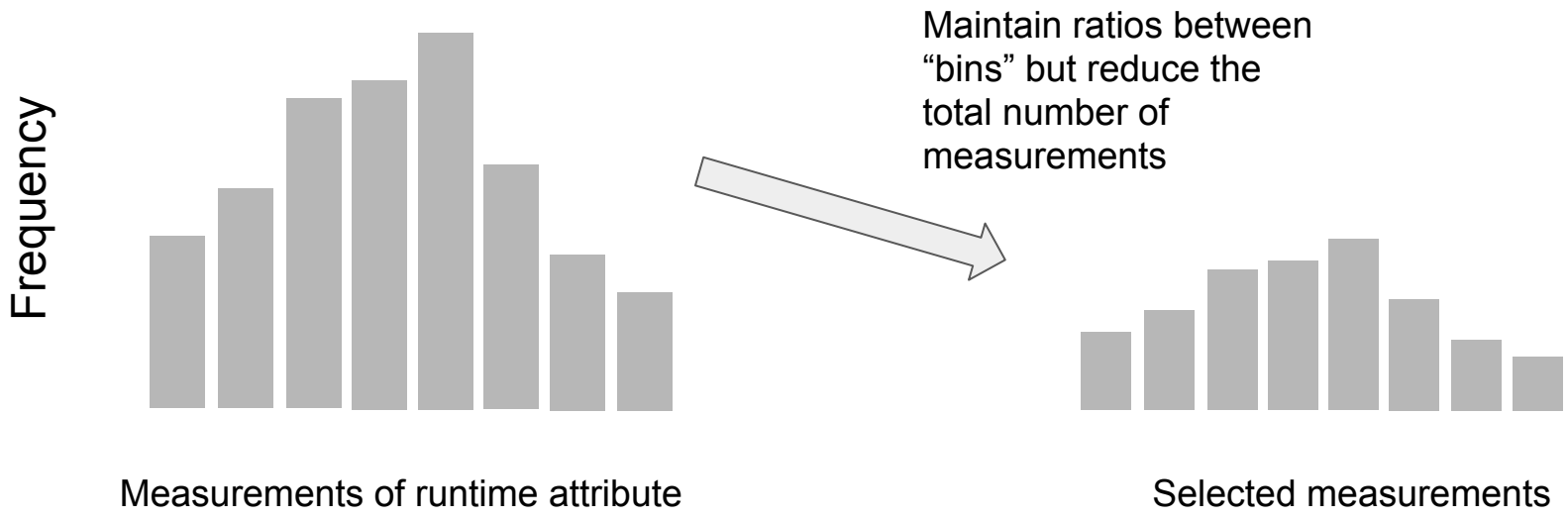
- Calculating a metric for difference

$$DIFF = \frac{STAT_{KERNEL} - STAT_{APP}}{STAT_{APP}} * 100(\%)$$

# How to select "best" set of input data?



- "Best" means differently to different usages
  - Some may be interested in a simple average
  - Or, shape of distribution for others
- In this paper, we introduced an algorithm to preserve the shape of distribution while reducing the size of data



# Case Studies

# Experiment Configuration

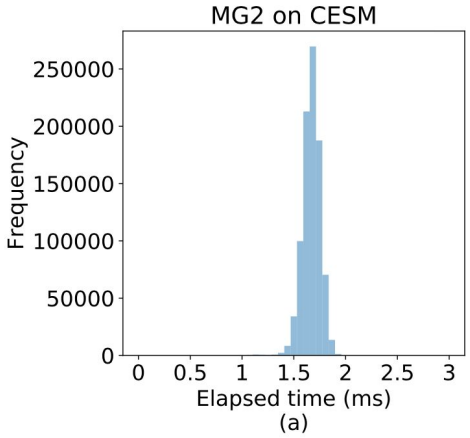


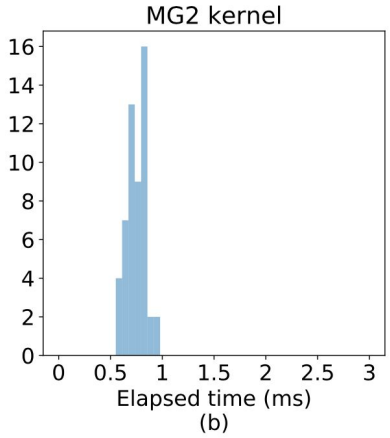
- System
  - Yellowstone computing cluster of National Center for Atmospheric Research (NCAR): 2.6GHz Intel Xeon E5-2670, 16 cores per node
  - Intel Fortran Compiler 16.0.1
- Applications
  - Community Earth System Model (CESM)
    - Morrison-Gettelman Cloud Physics 2 on **630 MPI ranks** and 2 OpenMP threads per a MPI rank on **42 computing nodes**
    - Rapid Radiative Transfer Model for General Circulation Models (RRTMG) Longwave Radiation Physics with the same runtime configuration to MG physics **except only one MPI rank for atmospheric component**
  - Linear Algebra Package (LAPACK)
    - Singular Value Decomposition Routine (**DGESVD**)
    - Sequential Test Program

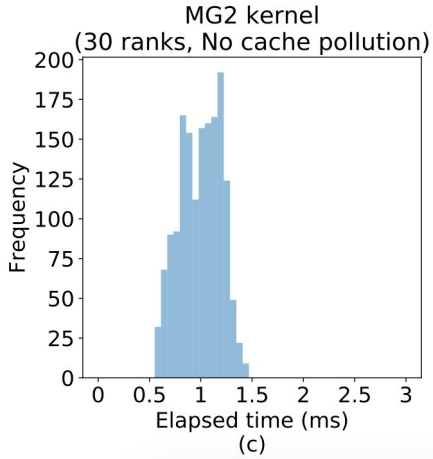
# MG2 kernel

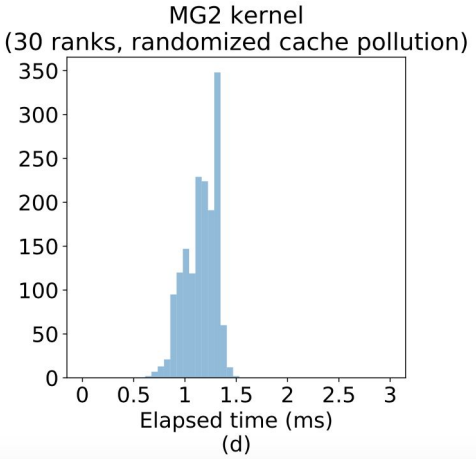


- Elapsed time for MG2 kernel
  - MG2 kernel is one of time consuming cloud physics routine in CESM*




| Stat. type | Value (a) | Value (b) | Diff(%) (a) ~ (b) | Value (d) | Diff(%) (a) ~ (d) |
|---|---|---|---|---|---|
| Mean (ms) | 1.67 | 0.75 | -55 | 1.16 | -30.8 |
| (min., max.) | (1.0, 2.5) | (0.6, 1.0) | (-42.5, -62.4) | (0.65, 1.53) | (-34.6, -38.8) |
| Std. dev. | 0.12 | 0.47 | 299.7 | 0.35 | 198 |
| Skew | -0.76 | -0.44 | -42.2 | -0.54 | -29 |

# Techniques to improve kernel representation



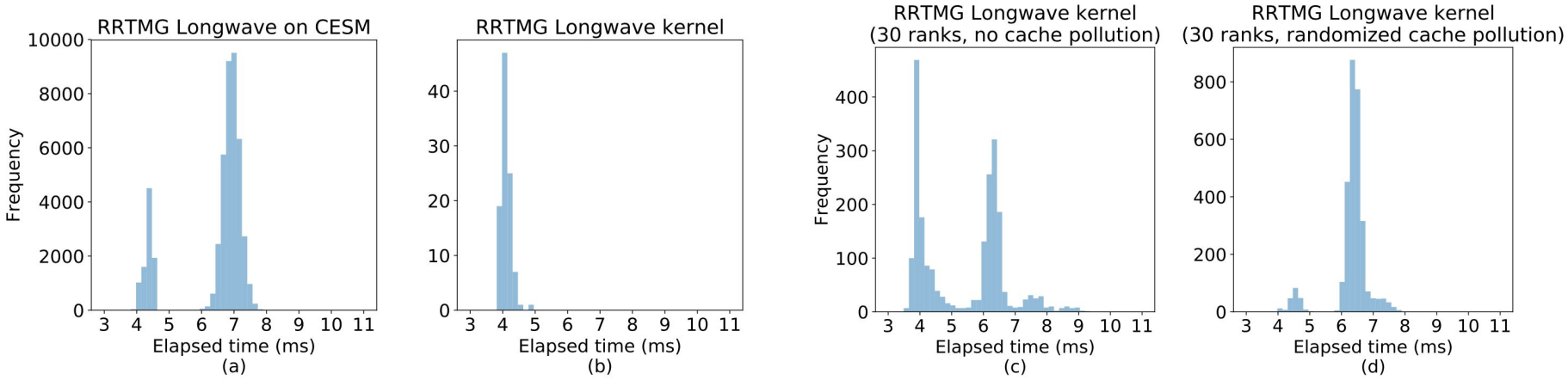
- A cache pollution method
  - Increment values of each entry of an array from an element index that is randomly selected
  - Repeat the writing one more time

- Repeat kernel execution on multiple MPI ranks
  - Create multiple MPI ranks and run the same kernel on each ranks

# RRTMG Longwave kernel



- Elapsed time for RRTMG Longwave kernel

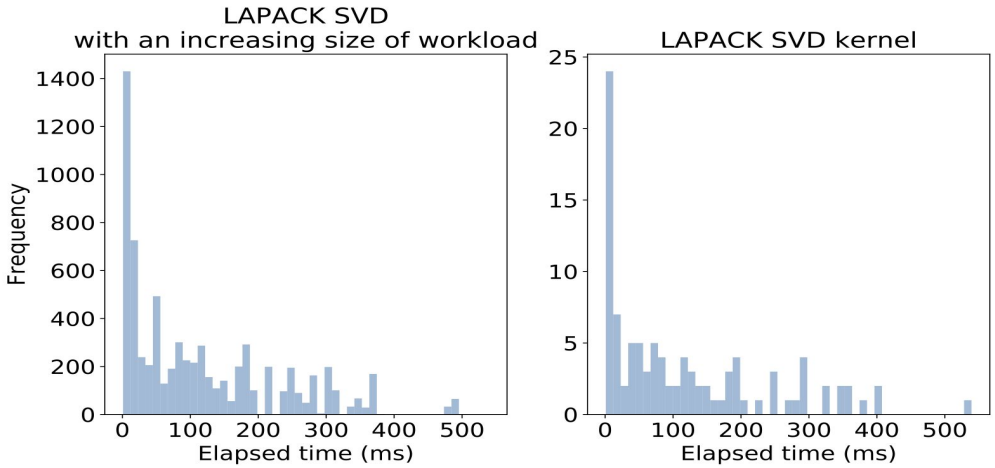



| Stat. type | Value (a) | Value (b) | Diff(%) (a) ~ (b) | Value (d) | Diff(%) (a) ~ (d) |
|---|---|---|---|---|---|
| Mean (ms) | 6.44 | 4.12 | -36 | 6.35 | -1.4 |
| (min., max.) | (3.84 7.8) | (3.83, 4.95) | (-0.3, -36.5) | (4.02, 7.9) | (-4.7, -1.3) |

# SVD routine in LAPACK



- Elapsed time is measured for SVD routines of LAPACK
  - Increasing workload from 64X64 matrix to 120X92

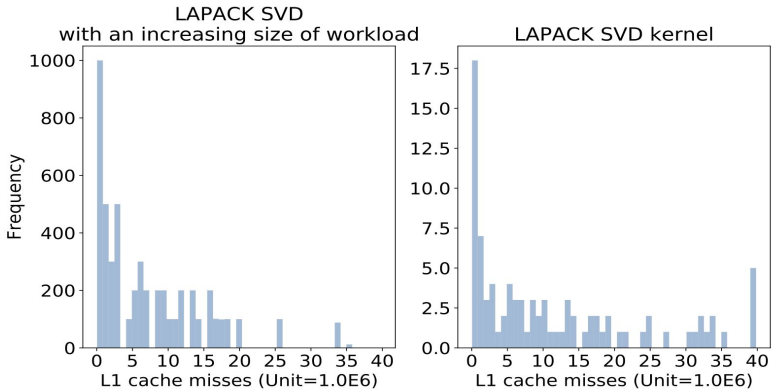



| Stat. type | SVD | SVD kernel | Diff(%) |
|---|---|---|---|
| Mean (ms) | 114 | 118 | 2.9 |
| (min., max.) | (1.0, 498) | (2.7, 539) | (-17.1, 8.3) |
| Std. dev. | 0.46 | 0.46 | 0.1 |
| Skew | 1.07 | 0.98 | -8.5 |

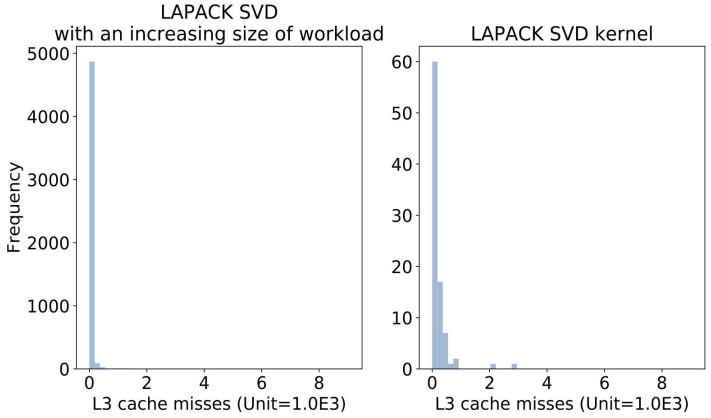
# SVD routine in LAPACK



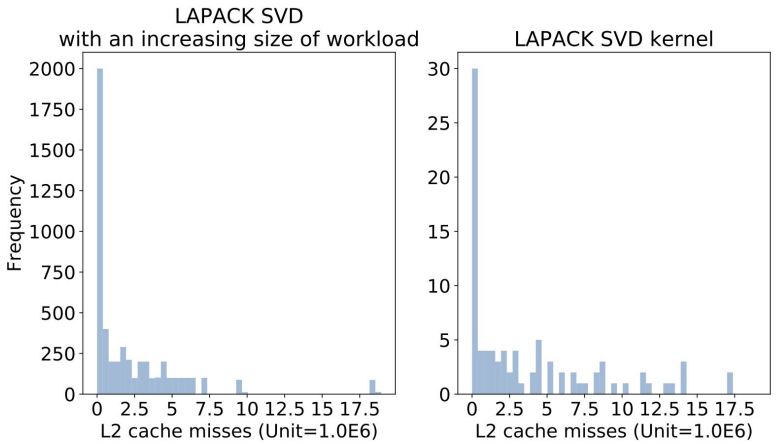
- PAPI cache counters for the same SVD routine




**L1 cache misses**




**L3 cache misses**




**L2 cache misses**

- Not fully automated yet.
- User may need to modify build process to link with PAPI library

# Source code coverage



- Original code

```
MODULE calc_mod
   PUBLIC calc
CONTAINS
   SUBROUTINE calc(i, j, output, out2, out3)
      INTEGER, INTENT(IN) :: i, j
      real, INTENT(OUT), dimension(:,:) :: out3, output, out2
      IF ( i > j ) THEN
         output(i,j) = i - j
         out2(i, j) = 2*(i-j)
         out3(i, j) = 3*(i-j)
      ELSE
         output(i,j) = j - i
         out2(i, j) = 2*(j-i)
         out3(i, j) = 3*(j-i)
      END IF
   END SUBROUTINE
END MODULE
```

- Annotated code

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!! 2 conditional blocks exist in this file
!! 2 conditional blocks are executed at least once among all
the conditional blocks.
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

MODULE calc_mod
   PUBLIC calc
CONTAINS
   SUBROUTINE calc(i, j, output, out2, out3)
...
      IF ( i > j ) THEN
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!! Total number of visits: 60
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      ELSE
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!! Total number of visits: 100
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      END IF
   END SUBROUTINE
END MODULE
```

# Conclusion



- Summary
  - KGen: an automated Fortran kernel generator
  - KGen representativeness extension:
    - Provides a quantitative metrics for the degree of kernel representation
    - Allows to improve kernel representation
- Future works
  - Analysis of cache pollution methods
  - Automated PAPI measurements
  - Better support for newer Fortran spec.
  - Better support for pointer analysis

# Thank you!

# Q & A

Funded partially by Intel Parallel Computing Center focused on Weather and Climate Simulation (IPCC-WACS)

KGen Github repository: https://github.com/NCAR/KGen
Further questions and comments to: kgen@ucar.edu

# Use Cases

# Use case 1 - Simulation Verification



- How to verify that a new simulation is consistent with previous simulation results?

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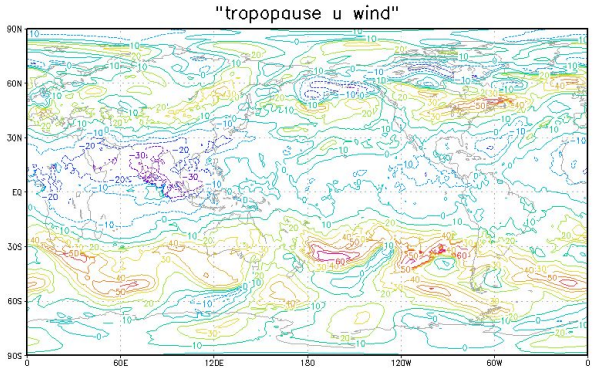
- How to verify that a new simulation is consistent with previous simulation results?

Reference CESM simulation on A system

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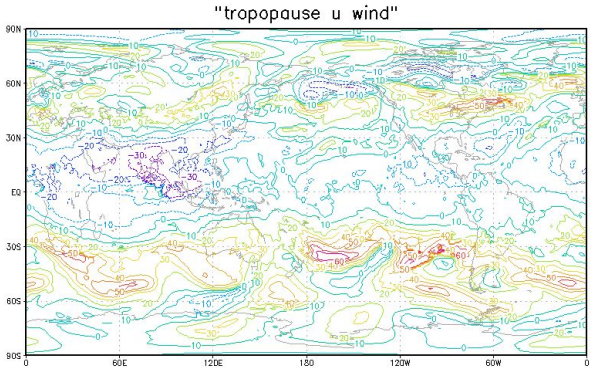
New CESM simulation on B system



# Use case 1 - Simulation Verification



- We found several variables from two simulations were **slightly different** between system A and B
- **Challenging to find a root cause** mainly due to:
  - Linear combinations of 120 physical variables
  - Several hours to run one-year sim. on 900 cores
- **Morrison-Gettelman(MG)1** microphysics
  - modifies many of the “suspicious” variables
- MG1 **kernel is generated** using KGen
  - Performed experiments using the kernel
  - Located one line that starts to show the inconsistency
- The root cause: **Fused-Multiply-Add(FMA)**
  - Without FMA, the kernel returned a reasonable RMS difference

# Use case 2 - Performance Optimization



- MG2 Kernel
  - One of time consuming routines in CESM*
  - ~2X speedup on Intel SandyBridge CPU
- Customized Benchmark Suite
  - MG2 is a part of benchmark suite for NCAR Wyoming Supercomputing Center (NWSC) procurement
- NCAR Kernel Repository
  - https://github.com/NCAR/kernelOptimization
  - ~40 kernels are generated. Being optimized internally and externally(compiler vendors and Int'l collaborators)
  - Trying to standardize testing method and reporting format

# Other potential use cases



- Unit test generation
  - A region of codes can be extracted as a test case
  - Data for driving test and verifying the code are also generated simultaneously
- Debugging large application
  - No need to use queuing system
  - Focus on the region of interesting code
- And more
  - A kernel is a yet another software ready to be built/run
  - An use case is upto user's needs and imagination

# KGen users



- Current users
  - Being used and/or evaluated by individuals mostly within climate/weather simulation community
    - NOAA Geophysical Fluid Dynamics Lab., ETH Zurich, U of Hamburg, Oak Ridge Nat'l Lab., U of Tennessee, U of Utah
    - Interested in performance optimization, porting to new processor, and enhancing unit test framework
- New users
  - KGen is available to "early-adopters"
    - https://github.com/NCAR/KGen
    - Welcome your opinion and comments on using KGen ( kgen@ucar.edu )
  - Welcome new users from other scientific fields too

# Back-ups

# Kernels in Scientific Computing



- Definition used in the paper
  - “a self-contained program that embodies essential performance characteristics of the node-level aspects of an application.”(Janssen, 2011)
- Related Research
  - Pioneering work by Heroux by defining a new role of kernel (Heroux, 2009)
  - Performance characterization by a kernel (Akel, 2013)
  - Assessing the role of mini-app (Barrett, 2015)
- Usage in practice
  - Benchmarks: STREAMS, Livermore Loops
  - Mantevo Project: A 2013 R&D 100 Award. the Mantevo Miniapp Suite
  - UK Mini-App Consortium: Many mini-apps including CloverLeaf
  - FIBER: A suite of mini-apps maintained by RIKEN Advanced Institute for Computational Science
  - DOE Exascale Co-design Centers: Exascale Co-Design Center for

# Kernel Generation



- Kernel Generation Methods
  - Manual vs. Automatic
  - Creates from scratch by whom knows original software well
  - Extracts partially or entirely from original software
- Difficulties in extracting a kernel manually
  - Manual searching of declarations for variables used in a kernel
  - Data preparation for deriving kernel execution
  - Especially time-consuming (AND error-prone) when:
    - there are large numbers of inputs/outputs
    - deep hierarchy of structured data types
    - scattered in many separate source files
    - heavily uses external libraries
  - Even with correctly generated kernels, it is, in practice, hard problem to verify the extracted kernel behaves “sufficiently close” to original application.

# Automated Kernel Generation



- Static (and dynamic) analysis of software
  - Generally uses features of a compiler or an analysis framework
  - Applies to source-code level or intermittent-code level
  - State information collected from source-code instrumentation or memory/cache H/W
- Previous work
  - Code Isolator(Lee, 2005): Based on SUIF compiler, source-code level
  - Codelet Finder(CAPS[*1]): Based on another CAPS product(ASTEX[*2]), source-code level
  - ROSE Outliner(Liao, 2010): Based on ROSE[*3] framework, source-code level
  - CERE(Castro, 2015): Based on LLVM. intermittent-code level
- Automation approaches in this paper
  - Based on Python. F2PY[*4] Fortran parser is integrated
  - AST search to decide minimum set of Fortran statements for a stand-alone executable

# A kernel generation example



**program.F90**

```
PROGRAM calc
  USE update_mod, only : &
    update
  INCLUDE 'mpif.h'
  INTEGER t, rank, N, err
  CALL mpi_init(err)
  CALL mpi_comm_size(...)
  CALL mpi_comm_rank(...)
  DO t=1,10
    CALL update(rank, N)
  END DO
  CALL mpi_finialize(err)
END PROGRAM
```

**update_mod.F90**

```
MODULE update_mod
  USE calc_mod, only : calc
  PUBLIC update
CONTAINS
  SUBROUTINE update(rank, N)
    INCLUDE 'mpif.h'
    INTEGER, INTENT(IN)::rank,N
    INTEGER :: i, j,err,lsum,gsum(N)
    INTEGER :: output(COL,ROW)
    gsum = 0
    DO i=1,COL
      DO j=1,ROW

        CALL calc(i, j, output)
      END DO
    END DO
    lsum = SUM(output)
    CALL mpi_gather(lsum, …)
    IF (rank==0) THEN
      print *,'global sum=', SUM(gsum)
    END IF
  END SUBROUTINE
END MODULE
```

**calc_mod.F90**

```
MODULE calc_mod
  PUBLIC calc
CONTAINS
  SUBROUTINE calc(i, j, output)
    INTEGER, INTENT(IN) :: i, j
    INTEGER, INTENT(OUT), &
        dimension(:,:) :: output
    CALL print_msg('start')
    output(i,j) = i + j
    CALL print_msg('finish')
  END SUBROUTINE
  SUBROUTINE print_msg(msg)
    CHARACTER(*),INTENT(IN):: &
      msg
    PRINT *, msg
  END SUBROUTINE
END MODULE
```

# A kernel generation example



**program.F90**

```
PROGRAM calc
  USE update_mod, only : &
    update
  INCLUDE 'mpif.h'
  INTEGER t, rank, N, err
  CALL mpi_init(err)
  CALL mpi_comm_size(...)
  CALL mpi_comm_rank(...)
  DO t=1,10
    CALL update(rank, N)
  END DO
  CALL mpi_finialize(err)
END PROGRAM
```

**update_mod.F90**

```
MODULE update_mod
  USE calc_mod, only : calc
  PUBLIC update
CONTAINS
  SUBROUTINE update(rank, N)
    INCLUDE 'mpif.h'
    INTEGER, INTENT(IN)::rank,N
    INTEGER :: i, j,err,lsum,gsum(N)
    INTEGER :: output(COL,ROW)
    gsum = 0
    DO i=1,COL
      DO j=1,ROW
        !$KGEN callsite calc
        CALL calc(i, j, output)
      END DO
    END DO
    lsum = SUM(output)
    CALL mpi_gather(lsum, …)
    IF (rank==0) THEN
      print *,'global sum=', SUM(gsum)
    END IF
  END SUBROUTINE
END MODULE
```

Call-site

**calc_mod.F90**

```
MODULE calc_mod
  PUBLIC calc
CONTAINS
  SUBROUTINE calc(i, j, output)
    INTEGER, INTENT(IN) :: i, j
    INTEGER, INTENT(OUT), &
       dimension(:,:) :: output
    CALL print_msg('start')
    output(i,j) = i + j
    CALL print_msg('finish')
  END SUBROUTINE
  SUBROUTINE print_msg(msg)
    CHARACTER(*),INTENT(IN):: &
      msg
    PRINT *, msg
  END SUBROUTINE
END MODULE
```

Kernel

# A kernel generation example



**program.F90**

```
PROGRAM calc
  USE update_mod, only : &
    update
  INCLUDE 'mpif.h'
  INTEGER t, rank, N, err
  CALL mpi_init(err)
  CALL mpi_comm_size(...)
  CALL mpi_comm_rank(...)
  DO t=1,10
    CALL update(rank, N)
  END DO
  CALL mpi_finialize(err)
END PROGRAM
```

**update_mod.F90**

```
MODULE update_mod
  USE calc_mod, only : calc
  PUBLIC update
CONTAINS
  SUBROUTINE update(rank, N)
    INCLUDE 'mpif.h'
    INTEGER, INTENT(IN)::rank,N
    INTEGER :: i, j,err,lsum,gsum(N)
    INTEGER :: output(COL,ROW)
    gsum = 0
    DO i=1,COL
      DO j=1,ROW
        !$KGEN callsite calc
        CALL calc(i, j, output)
      END DO
    END DO
    lsum = SUM(output)
    CALL mpi_gather(lsum, …)
    IF (rank==0) THEN
      print *,'global sum=', SUM(gsum)
    END IF
  END SUBROUTINE
END MODULE
```

Call-site

**calc_mod.F90**

```
MODULE calc_mod
  PUBLIC calc
CONTAINS
  SUBROUTINE calc(i, j, output)
    INTEGER, INTENT(IN) :: i, j
    INTEGER, INTENT(OUT), &
       dimension(:,:) :: output
    CALL print_msg('start')
    output(i,j) = i + j
    CALL print_msg('finish')
  END SUBROUTINE
  SUBROUTINE print_msg(msg)
    CHARACTER(*),INTENT(IN):: &
      msg
    PRINT *, msg
  END SUBROUTINE
END MODULE
```

Kernel

# Generated kernel files



**kernel_driver.f90**

```
PROGRAM kernel_driver
  ...
  OPEN(UNIT=kgen_unit, &
     FILE=kgen_filepath, …)
  ...
  CALL update(kgen_unit)

  CLOSE(kgen_unit)
  ...
END PROGRAM
```

**update_mod.F90**

```
MODULE update_mod ...
CONTAINS
  SUBROUTINE update(kgen_unit)
    INTEGER, INTENT(IN) :: kgen_unit
    ...
    CALL kgen_init_check(check_status, tolerance)
    READ(UNIT=kgen_unit) i
    READ(UNIT=kgen_unit) j
    …
    READ(UNIT=kgen_unit) ref_output
    CALL calc(i, j, output) ! call to kernel
    CALL kgen_verify_integer_4_dim2(...
    CALL kgen_print_check("calc", check_status)
    CALL system_clock(start_clock, rate_clock)
      …
    CALL system_clock(stop_clock, rate_clock)
    PRINT *, "calc : Time per call (usec): ", ...

    CONTAINS
      SUBROUTINE kgen_verify_integer_4_dim2(...)
        …
        IF (ALL(var==ref_var)) THEN ...
        END IF
      END SUBROUTINE
  END SUBROUTINE
END MODULE
```

**calc_mod.F90**

```
MODULE calc_mod
  ...
CONTAINS
  SUBROUTINE calc(i, j, output)
    ...
    !kgen_excluded CALL &
      print_msg('start')
    output(i,j) = i + j
    !kgen_excluded CALL &
     print_msg('finish')
  END SUBROUTINE
END MODULE
```

# Generated kernel files



**kernel_driver.f90**

```
PROGRAM kernel_d
  OPEN(UNIT=kgen_unit, &
    FILE=kgen_filepath, …)
  ...
  CALL update(kgen_unit)

  CLOSE(kgen_unit)
  ...
END PROGRAM
```

Open data file to read

**update_mod.F90**

```
MODULE update_mod ...
CONTAINS
  SUBROUTINE update(kgen_unit)
    INTEGER, INTENT(IN) :: kgen_unit
    ...
    CALL kgen_init_check(check_status, tolerance)
    READ(UNIT=kgen_unit) i
    READ(UNIT=kgen_unit) j
    …
    READ(UNIT=kgen_unit) ref_output
    CALL calc(i, j, output) ! call to kernel
    CALL kgen_verify_integer_4_dim2(...
    CALL kgen_print_check("calc", check_status)
    CALL system_clock(start_clock, rate_clock)
      …
    CALL system_clock(stop_clock, rate_clock)
    PRINT *, "calc : Time per call (usec): ", ...

    CONTAINS
      SUBROUTINE kgen_verify_integer_4_dim2(...)
        …
        IF (ALL(var==ref_var)) THEN ...
        END IF
      END SUBROUTINE
  END SUBROUTINE
END MODULE
```

**calc_mod.F90**

```
MODULE calc_mod
  ...
CONTAINS
  SUBROUTINE calc(i, j, output)
    ...
    !kgen_excluded CALL &
      print_msg('start')
    output(i,j) = i + j
    !kgen_excluded CALL &
     print_msg('finish')
  END SUBROUTINE
END MODULE
```

# Generated kernel files



**kernel_driver.f90**

```
PROGRAM kernel_driver
  ...
  OPEN(UNIT=kgen_unit, &
     FILE=kgen_filepath, …)
  ...
  CALL update(kgen_unit)

  CLOSE(kgen_unit)
  ...
END PROGRAM
```

**update_mod.F90**

```
MODULE update_mod ...
CONTAINS
  SUBROUTINE update(kgen_unit)
    INTEGER, INTENT(IN) :: kgen_unit
    ...
    CALL kgen_init_check(check_status, tolerance)
    READ(UNIT=kgen_unit) i
    READ(UNIT=kgen_unit) j
    …
    READ(UNIT=kgen_unit) ref_output
    CALL calc(i, j, output) ! call to kernel
    CALL kgen_verify_integer_4_dim2(...)
    CALL kgen_print_check("calc", check_status)
    CALL system_clock(start_clock, rate_clock)
      …
    CALL system_clock(stop_clock, rate_clock)
    PRINT *, "calc : Time per call (usec): ", ...

    CONTAINS
      SUBROUTINE kgen_verify_integer_4_dim2(...)
        …
        IF (ALL(var==ref_var)) THEN ...
        END IF
      END SUBROUTINE
  END SUBROUTINE
END MODULE
```

Read data

Verify result

Measure timing

**calc_mod.F90**

```
MODULE calc_mod
  ...
CONTAINS
  SUBROUTINE calc(i, j, output)

    !kgen_excluded CALL &
      print_msg('start')
    output(i,j) = i + j
    !kgen_excluded CALL &
    !      int_msg('finish')
  END SUBROUTINE
END MODULE
```

# Generated kernel files



**kernel_driver.f90**

```
PROGRAM kernel_driver
  ...
  OPEN(UNIT=kgen_unit, &
     FILE=kgen_filepath, …)
  ...
  CALL update(kgen_unit)

  CLOSE(kgen_unit)
  ...
END PROGRAM
```

**update_mod.F90**

```
MODULE update_mod ...
CONTAINS
  SUBROUTINE update(kgen_unit)
    INTEGER, INTENT(IN) :: kgen_unit
    ...
    CALL kgen_init_check(check_status, tolerance)
    READ(UNIT=kgen_unit) i
    READ(UNIT=kgen_unit) j
    …
    READ(UNIT=kgen_unit) ref_output
    CALL calc(i, j, output) ! call to kernel
    CALL kgen_verify_integer_4_dim2(...
    CALL kgen_print_check("calc", check_status)
    CALL system_clock(start_clock, rate_clock)
      …
    CALL system_clock(stop_clock, rate_clock)
    PRINT *, "calc : Time per call (usec): ", ...

    CONTAINS
      SUBROUTINE kgen_verify_integer_4_dim2(...)
        …
        IF (ALL(var==ref_var)) THEN ...
        END IF
      END SUBROUTINE
  END SUBROUTINE
END MODULE
```

**calc_mod.F90**

```
MODULE calc_mod
  ...
CONTAINS
  SUBROUTINE calc(i, j, output)
    ...
    !kgen_excluded CALL &
      print_msg('start')
    output(i,j) = i + j
    !kgen_excluded CALL &
     print_msg('finish')
  END SUBROUTINE
END MODULE
```

kernel

# Generated kernel files



**kernel_driver.f90**

```
PROGRAM kernel_driver
  ...
  OPEN(UNIT=kgen_unit, &
     FILE=kgen_filepath, …)
  ...
  CALL update(kgen_unit)

  CLOSE(kgen_unit)
  ...
END PROGRAM
```

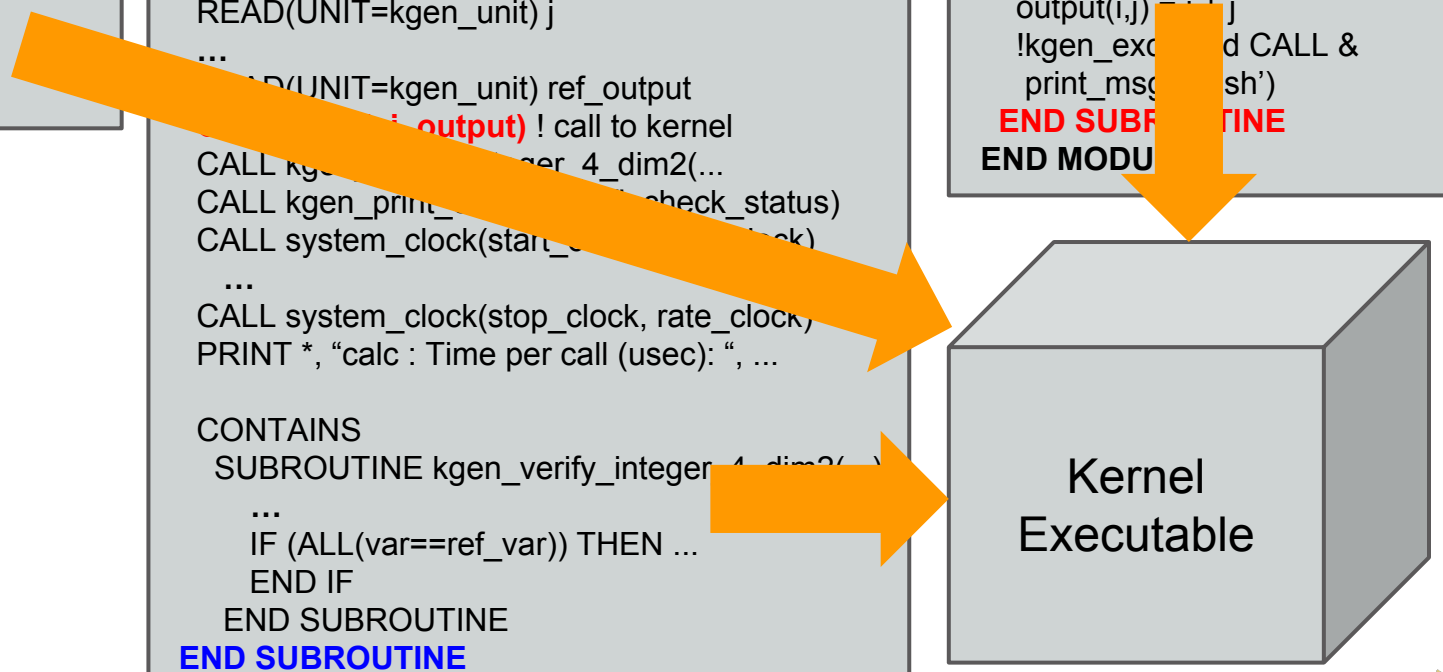
**update_mod.F90**

```
MODULE update_mod ...
CONTAINS
  SUBROUTINE update(kgen_unit)
    INTEGER, INTENT(IN) :: kgen_unit
    ...
    CALL kgen_init_check(check_status, tolerance)
    READ(UNIT=kgen_unit) i
    READ(UNIT=kgen_unit) j
    ...
    AD(UNIT=kgen_unit) ref_output
    output) ! call to kernel
    CALL kg                ger_4_dim2(...
    CALL kgen_print_       heck_status)
    CALL system_clock(start_c      ck)
      ...
    CALL system_clock(stop_clock, rate_clock)
    PRINT *, “calc : Time per call (usec): “, ...

    CONTAINS
      SUBROUTINE kgen_verify_integer_4_dim2(...)
        ...
        IF (ALL(var==ref_var)) THEN ...
        END IF
      END SUBROUTINE
  END SUBROUTINE
END MODULE
```

**calc_mod.F90**

```
MODULE calc_mod
  ...
CONTAINS
  SUBROUTINE calc(i, j, output)
    ...
    !kgen_excluded CALL &
      print_msg(‘start’)
    output(i,j) = i + j
    !kgen_exc      d CALL &
     print_msg     sh’)
  END SUBR      TINE
END MODU
```



# Generated instrumentation file



**update_mod.F90**

```
MODULE update_mod
CONTAINS
  SUBROUTINE update(rank, N)
    ...
    DO i=1,COL
      DO j=1,ROW
        !$KGEN callsite calc
        ...
        OPEN(UNIT=kgen_unit, FILE=kgen_filepath, …)
        ...
        WRITE(UNIT=kgen_unit) i
        WRITE(UNIT=kgen_unit) j
        ...
        CALL calc(i, j, output)
        ...
        WRITE(UNIT=kgen_unit) output
        ...
        CLOSE(UNIT=kgen_unit)
        ...
      END DO
    END DO
  END SUBROUTINE
END MODULE
```

# Generated instrumentation file



**update_mod.F90**

```
MODULE update_mod
CONTAINS
  SUBROUTINE update(rank, N)
    ...
    DO i=1,COL
      DO j=1,ROW
        !$KGEN callsite calc
        OPEN(UNIT=kgen_unit, FILE=kgen_filepath, …)
        WRITE(UNIT=kgen_unit) i
        WRITE(UNIT=kgen_unit) j
        ...
        CALL calc(i, j, output)
        ...
        WRITE(UNIT=kgen_unit) output
        …
        CLOSE(UNIT=kgen_unit)
        ...
      END DO
    END DO
  END SUBROUTINE
END MODULE
```

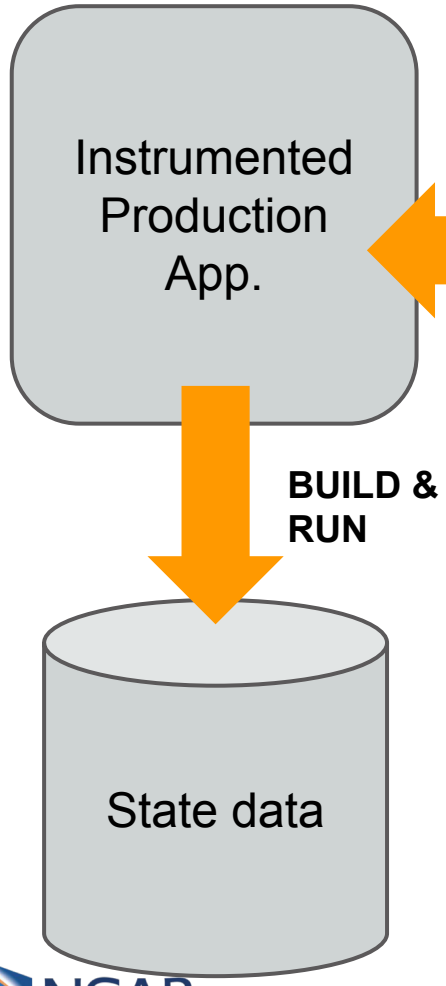
Open data file to write

write input variable

Write output variable

# Generated instrumentation file






**update_mod.F90**

```
MODULE update_mod
CONTAINS
  SUBROUTINE update(rank, N)
    ...
    DO i=1,COL
      DO j=1,ROW
        !$KGEN callsite calc
        ...
        OPEN(UNIT=kgen_unit, FILE=kgen_filepath, …)
        ...
        WRITE(UNIT=kgen_unit) i
        WRITE(UNIT=kgen_unit) j
        ...
        CALL calc(i, j, output)
        ...
        WRITE(UNIT=kgen_unit) output
        ...
        CLOSE(UNIT=kgen_unit)
        ...
      END DO
    END DO
  END SUBROUTINE
END MODULE
```