

# MODULE ONE: INTRODUCTION

Dr. Volker Weinberg | LRZ

# MODULE OVERVIEW

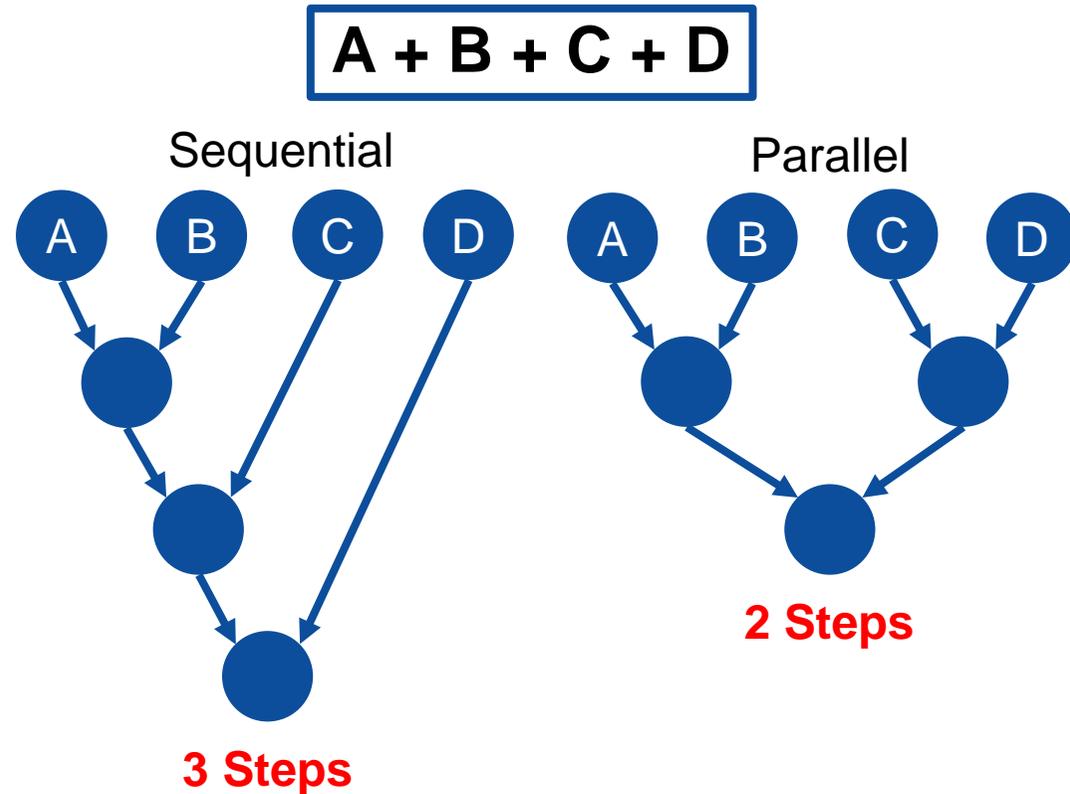
## Topics to be covered

- Introduction to parallel programming
- Common difficulties in parallel programming
- Introduction to OpenACC
- Parallel programming in OpenACC

# INTRODUCTION TO PARALLEL PROGRAMMING

# WHAT IS PARALLEL PROGRAMMING?

- “Performance Programming”
- Parallel programming involves exposing an algorithm’s ability to execute in parallel
- This may involve breaking a large operation into smaller tasks (task parallelism)
- Or doing the same operation on multiple data elements (data parallelism)
- Parallel execution enables better performance on modern hardware

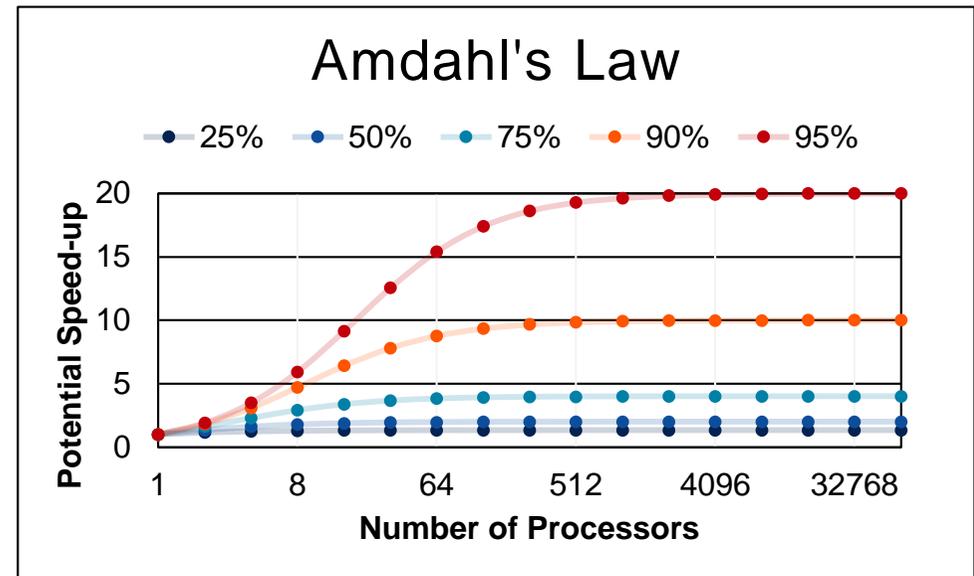


# AMDAHL'S LAW

# AMDAHL'S LAW

## Serialization Limits Performance

- Amdahl's law is an observation that how much speed-up you get from parallelizing the code is limited by the remaining serial part.
- Any remaining serial code will reduce the possible speed-up
- This is why it's important to focus on parallelizing the most time consuming parts, not just the easiest.



# APPLYING AMDAHL'S LAW

## Estimating Potential Speed-up

- What's the maximum speed-up that can be obtained by parallelizing 50% of the code?

$$1 / (100\% - 50\%) = 1 / (1.0 - 0.50) = 2.0X$$

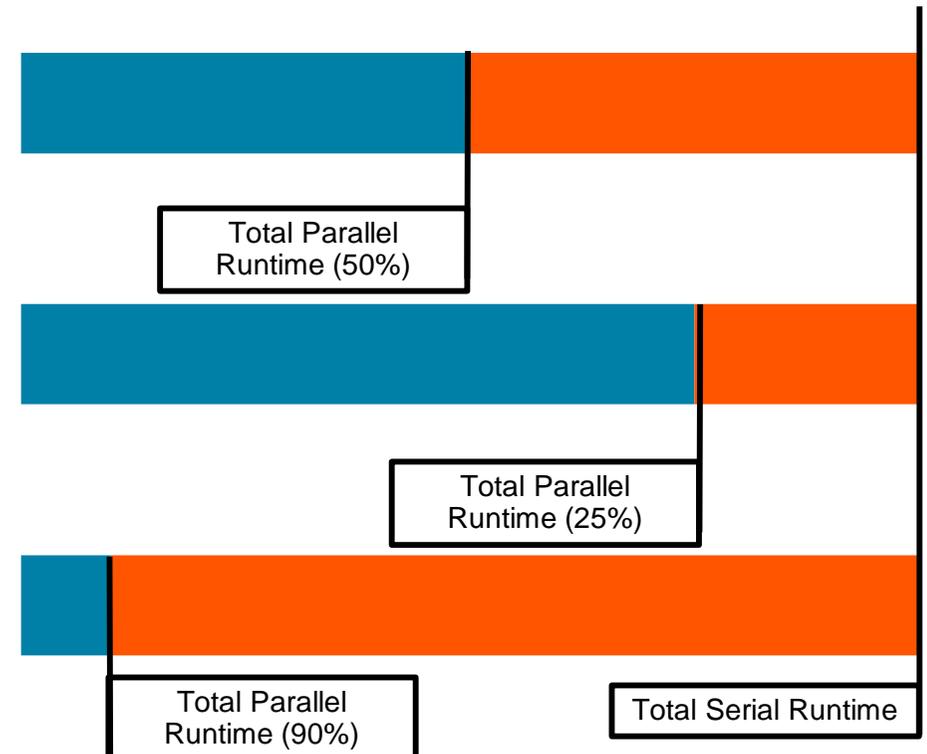
- What's the maximum speed-up that can be obtained by parallelizing 25% of the code?

$$1 / (100\% - 25\%) = 1 / (1.0 - 0.25) = 1.33X$$

- What's the maximum speed-up that can be obtained by parallelizing 90% of the code?

$$1 / (100\% - 90\%) = 1 / (1.0 - 0.90) = 10.0X$$

Maximum Parallel Speed-up



# INTRODUCTION TO OPENACC

**OpenACC** is a directives-based programming approach to **parallel computing** designed for **performance** and **portability** on CPUs and GPUs for HPC.

Add Simple Compiler Directive

```
main()  
{  
  <serial code>  
  #pragma acc kernels  
  {  
    <parallel code>  
  }  
}
```



# STANDARDS-BASED PARALLELISM

## MPI standard



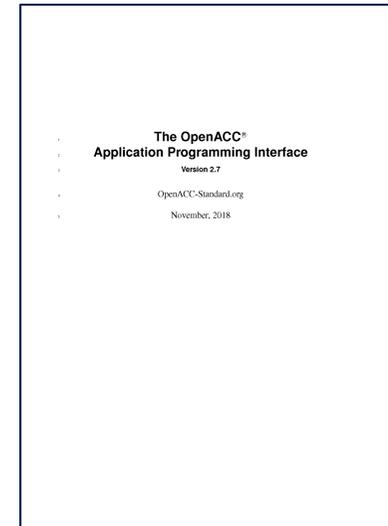
<https://www.mpi-forum.org/docs/>

## OpenMP standard



<https://www.openmp.org/specifications/>

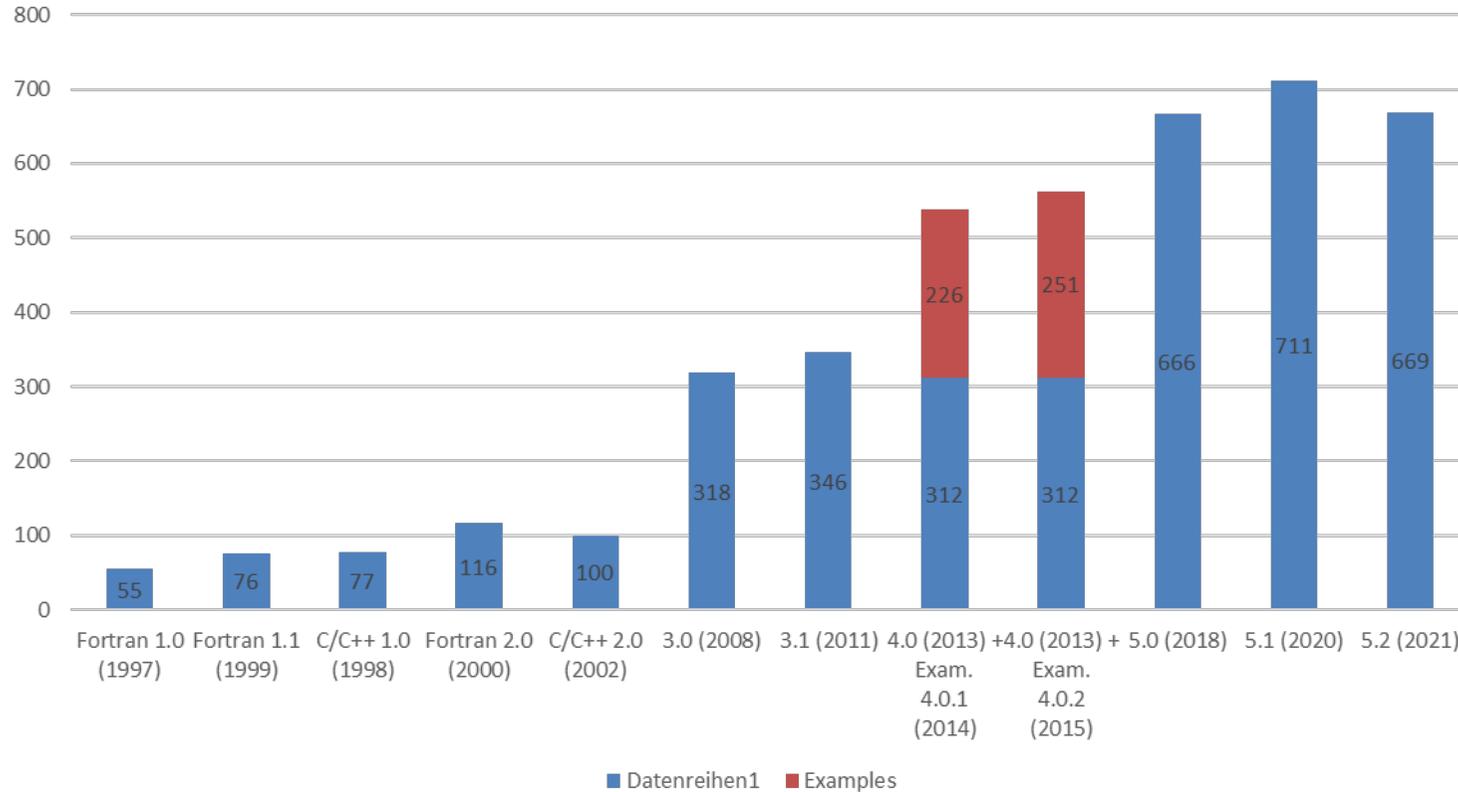
## OpenACC standard



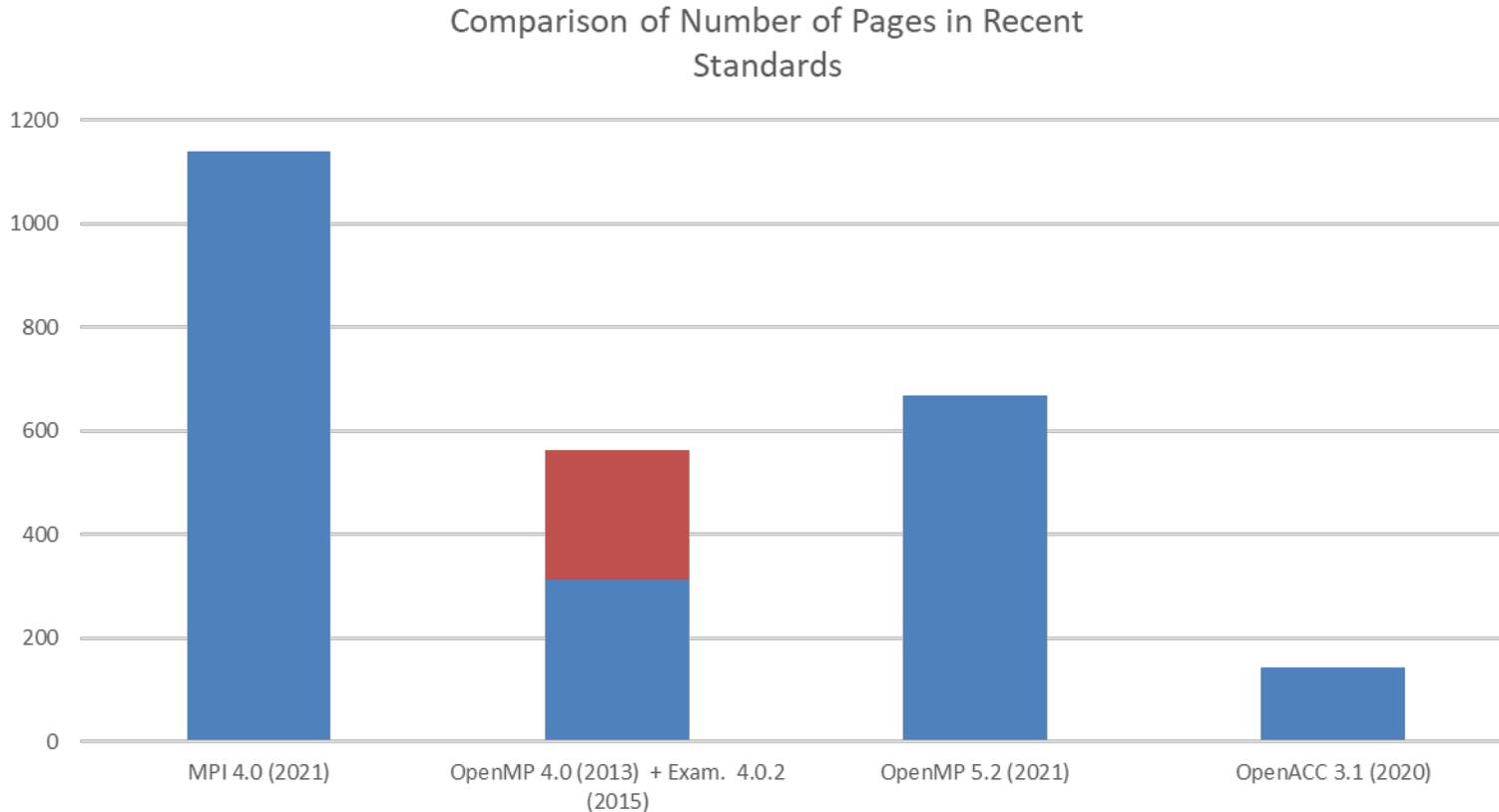
<https://www.openacc.org/specification>

# DEVELOPMENT OF OPENMP STANDARD

Number of Pages in OpenMP Standard



# COMPLEXITY OF RECENT STANDARDS



# 3 WAYS TO ACCELERATE APPLICATIONS

Applications

Libraries

Easy to use  
Most Performance

Compiler Directives

Easy to use  
Portable code

**OpenACC**

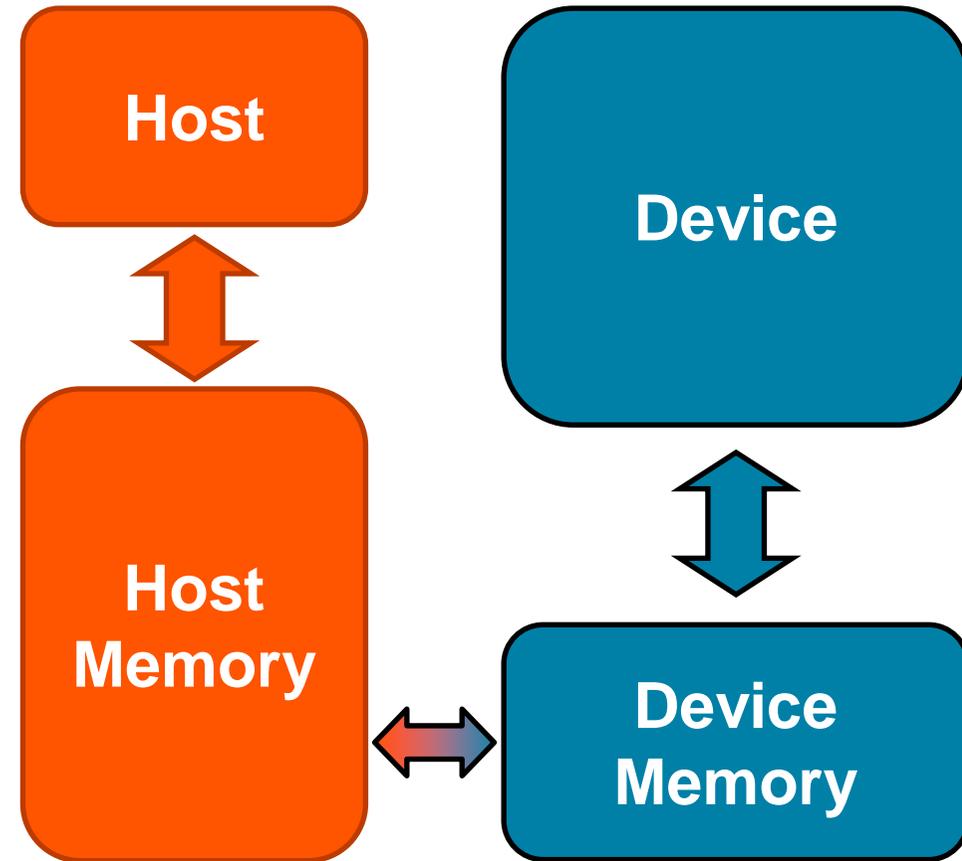
Programming Languages

Most Performance  
Most Flexibility

# OPENACC PORTABILITY

## Describing a generic parallel machine

- OpenACC is designed to be portable to many existing and future parallel platforms
- The programmer need not think about specific hardware details, but rather express the parallelism in generic terms
- An OpenACC program runs on a *host* (typically a CPU) that manages one or more parallel *devices* (GPUs, etc.). The host and device(s) are logically thought of as having separate memories.



# OPENACC

Three major strengths

Incremental

Single Source

Low Learning Curve

# OPENACC

## Incremental

- Maintain existing sequential code
- Add annotations to expose parallelism
- After verifying correctness, annotate more of the code

### Enhance Sequential Code

```
#pragma acc parallel loop  
for( i = 0; i < N; i++ )  
{  
    < loop code >  
}  
  
#pragma acc parallel loop  
for( i = 0; i < N; i++ )  
{  
    < loop code >  
}
```

Begin with a working sequential code.

Parallelize it with OpenACC.

Rerun the code to verify correct behavior, remove/alter OpenACC code as needed.

# OPENACC

## Incremental

- Maintain existing sequential code
- Add annotations to expose parallelism
- After verifying correctness, annotate more of the code

## Single Source

## Low Learning Curve

# OPENACC

## Supported Platforms

POWER  
Sunway  
x86 CPU  
x86 Xeon Phi  
NVIDIA GPU  
PEZY-SC

## Single Source

- Rebuild the same code on multiple architectures
- Compiler determines how to parallelize for the desired machine
- Sequential code is maintained

The compiler can **ignore** your OpenACC code additions, so the same code can be used for **parallel** or **sequential** execution.

```
int main(){  
  
...  
  
#pragma acc parallel loop  
for(int i = 0; i < N; i++)  
  < loop code >  
  
}
```

# OPENACC

## Incremental

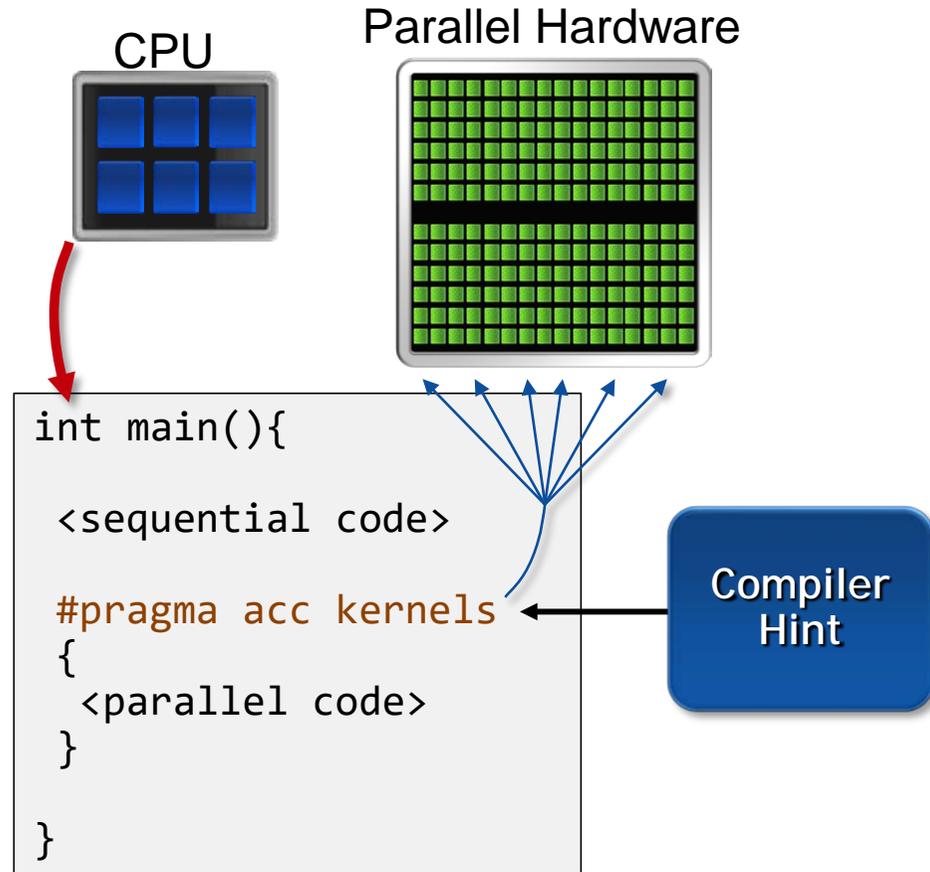
- Maintain existing sequential code
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## Single Source

- Rebuild the same code on multiple architectures
- Compiler determines how to parallelize for the desired machine
- Sequential code is maintained

## Low Learning Curve

# OPENACC



The programmer will give hints to the compiler about which parts of the code to parallelize.

The compiler will then generate parallelism for the target parallel hardware.

## Low Learning Curve

- OpenACC is meant to be easy to use, and easy to learn
- Programmer remains in familiar C, C++, or Fortran
- No reason to learn low-level details of the hardware.

# OPENACC

## Incremental

- Maintain existing sequential code
- Add annotations to expose parallelism
- After verifying correctness, annotate more of the code

## Single Source

- Rebuild the same code on multiple architectures
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## Low Learning Curve

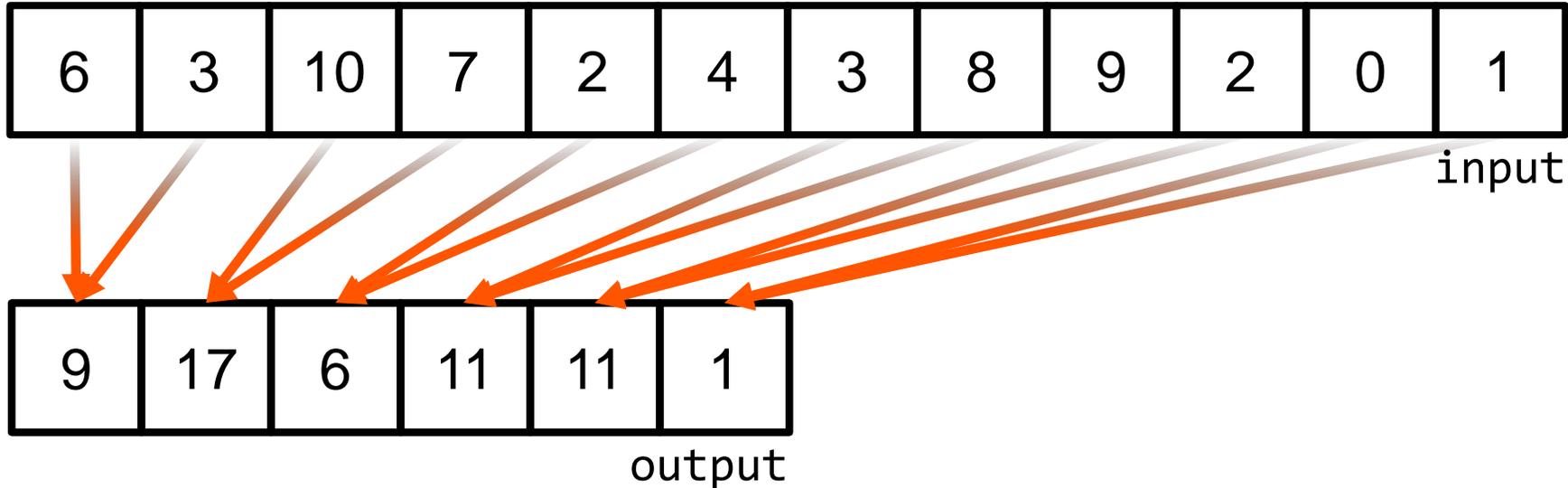
- OpenACC is meant to be easy to use, and easy to learn
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# EXPRESSING PARALLELISM WITH OPENACC

# CODING WITH OPENACC

## Array pairing example- serial

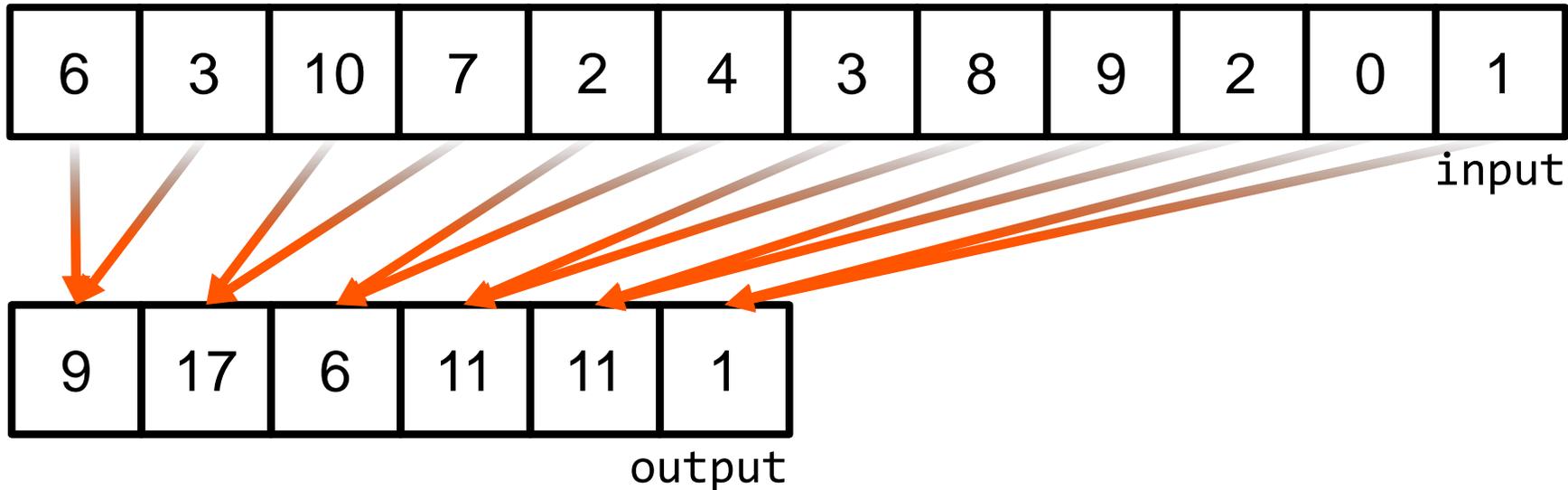
```
void pairing(int *input, int *output, int N){  
    for(int i = 0; i < N; i++){  
        output[i] = input[i*2] + input[i*2+1];  
    }  
}
```



# CODING WITH OPENACC

## Array pairing example - parallel

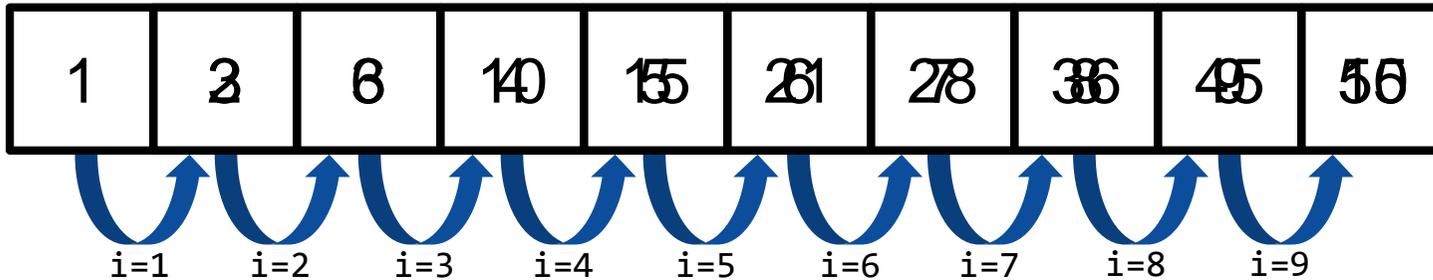
```
void pairing(int *input, int *output, int N){  
    #pragma acc parallel loop  
    for(int i = 0; i < N; i++){  
        output[i] = input[i*2] + input[i*2+1];  
    }  
}
```



# DATA DEPENDENCIES

Not all loops are parallel

```
void pairing(int *a, int N){  
    for(int i = 1; i < N; i++){  
        a[i] = a[i] + a[i-1];  
    }  
}
```

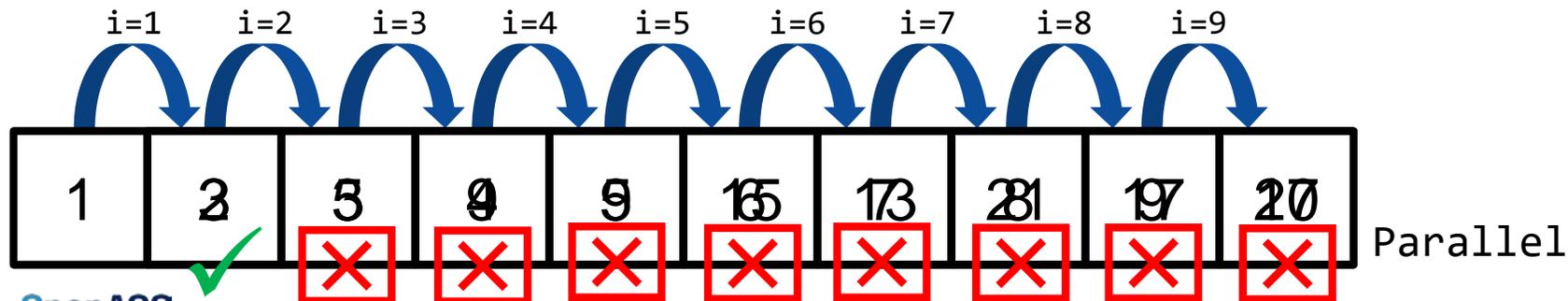
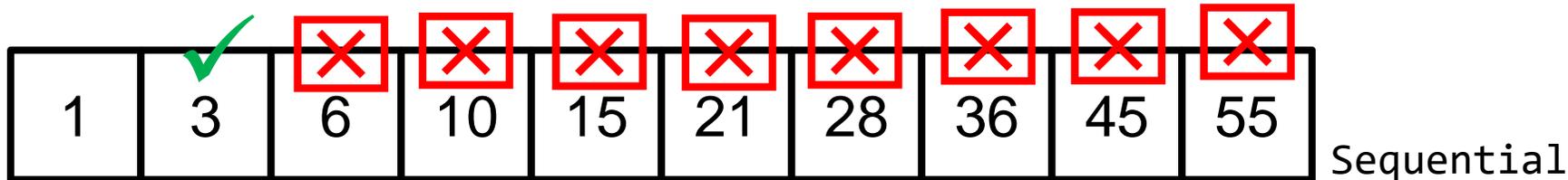


# DATA DEPENDENCIES

Not all loops are parallel

```
void pairing(int *a, int N){  
  pragma acc parallel loop  
  for(int i = 1; i < N; i++){  
    a[i] = a[i] + a[i-1];  
  }  
}
```

If we attempted to parallelize this loop we would get wrong answers due to a *forward dependency*.



# MODULE 1 REVIEW

# CLOSING SUMMARY

## Module One: Introduction

- Parallel programming is a technique of utilizing modern hardware to do lots of work all at once.
- Amdahl's law is the gravity of parallel programming, break this law at your own peril.
- Not all loops are parallel, but often can be rewritten to be parallelizable
- OpenACC is a high level model for generating parallel code from serial loops

# OPENACC RESOURCES

Guides • Talks • Tutorials • Videos • Books • Spec • Code Samples • Teaching Materials • Events • Success Stories • Courses • Slack • Stack Overflow



**FREE  
Compilers**

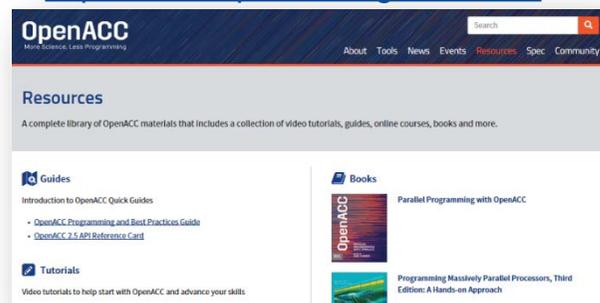
**PGI**  
Community  
EDITION



<https://www.openacc.org/community#slack>

## Resources

<https://www.openacc.org/resources>



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### Resources

A complete library of OpenACC materials that includes a collection of video tutorials, guides, online courses, books and more.

- Guides**
  - Introduction to OpenACC Quick Guides
  - OpenACC Programming and Best Practices Guide
  - OpenACC 2.5 API Reference Card
- Tutorials**
  - Video tutorials to help start with OpenACC and advance your skills
- Books**
  - Parallel Programming with OpenACC
  - Programming Massively Parallel Processors, Third Edition: A Hands-on Approach

## Compilers and Tools

<https://www.openacc.org/tools>



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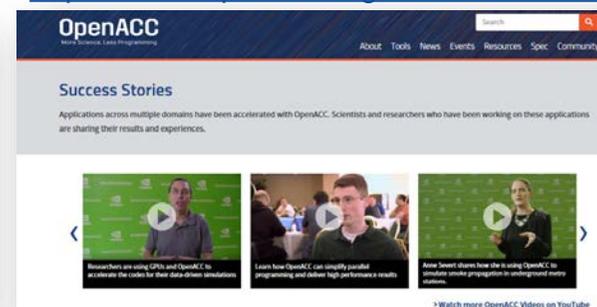
### Downloads & Tools

OpenACC compilers, profilers and debuggers are designed and available to download from multiple vendors and academic organizations.

- Commercial Compilers**
  - CRAY**  
THE SUPERCOMPUTER COMPANY  
Contact Cray Inc for more information.
  - PGI**  
PGI Accelerator Compilers with OpenACC Directives  
Contact National Supercomputing Center in Wuhan for more information.
- Open Source Compilers**
  - Intel**  
Intel Parallel Studio XE  
Includes initial support for OpenACC 2.5

## Success Stories

<https://www.openacc.org/success-stories>



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### Success Stories

Applications across multiple domains have been accelerated with OpenACC. Scientists and researchers who have been working on these applications are sharing their results and experiences.

- Researchers are using GPUs and OpenACC to accelerate the codes for their data-driven simulations.
- Learn how OpenACC can simplify parallel programming and deliver high performance results.
- Alison Sweet shares how she is using OpenACC to simulate smoke propagation in underground metro stations.

Watch more OpenACC Videos on YouTube

## Events

<https://www.openacc.org/events>



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### Events

The OpenACC Community organizes a variety of events throughout the year. Events vary from talks at conferences to workshops, hackathons, online courses and User Group meetings. Join our events around the world to learn OpenACC programming and to participate in activities with the OpenACC User Group.

- Hackathons**  
Hackathons are five day intensive hands-on mentoring sessions. They are designed to help computational scientists port their applications to GPUs using libraries, OpenACC, CUDA and other tools. They are currently lead by the Oak Ridge Leadership Computing Facility (OLCF) at the Oak Ridge National Laboratory (ORNL). For the full schedule and registration details please visit: <https://www.olcf.ornl.gov/training-event2017-gpu/>.
- 2017 Calendar**
  - 15** WORKSHOP  
Parallel Programming with OpenACC on CPUs and GPUs  
15 August 15, 2017 | Stanford University, Palo Alto, CA

# THANK YOU