Automatic task-based parallelization of Python codes

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MS12: Task-based Programming for Scientific Computing: Runtime Support

Outline

- Introduction
  - PLUTO
  - PyCOMPSs
- AutoParallel
  - Annotation
  - Architecture
- Evaluation
- Conclusions and Future Work

Introduction

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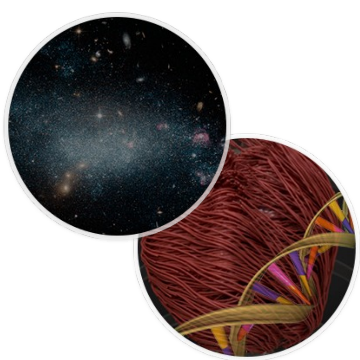
Motivation

Parallel Issues
- Identifying parallel regions
- Concurrency management
- Execution orchestration

Distributed Issues
- Remote execution
- Data transfers

Ease the development of distributed applications



THE GOAL:

Any field expert can scale up an application to hundreds of cores

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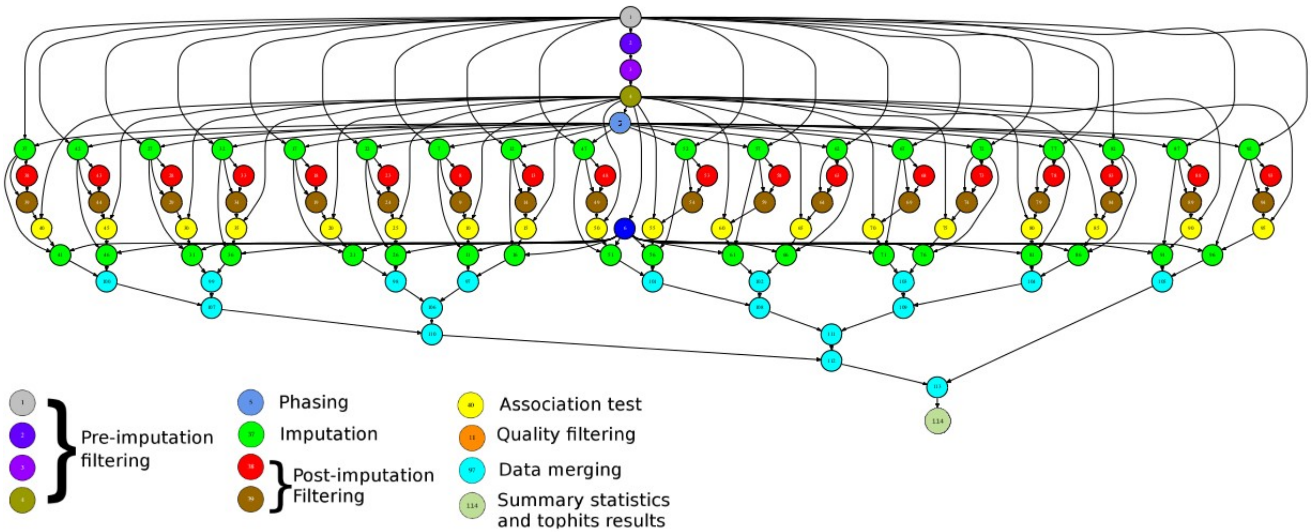
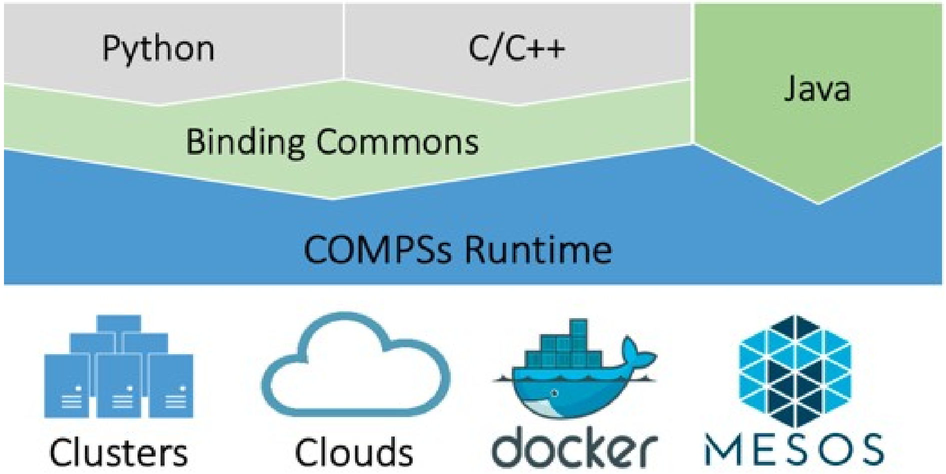
COMPSs

- Based on sequential programming
  - General purpose programming language + annotations
- Task-based programming model
  - Task is the unit of work
  - Implicit Workflow: Builds a task graph at runtime that expresses potential concurrency



COMPSs

- Infrastructure agnostic
  - Same application runs on clusters, grids, clouds and containers



- Supports other types of parallelism
  - Multi-threaded tasks (i.e., MKL kernels)
  - Multi-node tasks (i.e., MPI applications)
  - Non-native tasks (i.e., binaries)
  - Nested PyCOMPSs applications
  - Integration with BSC OmpSs

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PyCOMPSs Annotation

- Python decorators for task selection + synchronization API
  - Instance and class methods
  - Task data directions

```
@task(a=IN, b=IN, c=INOUT)
def multiply_acum(a, b, c):
    c += a * b
```

```
@task(returns=int)
def multiply(a, b, c):
    return c + a * b
```

```
@constraint(computingUnits="2")
@task(file=FILE_IN)
def my_task(x):
    ...
```

```
@binary(binary="sed")
@task(f=FILE_INOUT)
def binary_task(flag, expr, f):
    pass
```

```
@task(returns=dict)
def wordcount(block):
  ...

@task(result=INOUT)
def reduce(result, pres):
  ...

def main(a, b, c):
  for block in data:
    pres = wordcount(block)
    reduce(result, pres)
  result = compss_wait_on(result)

  # f = compss_open(fn)
  # compss_delete_file(f)
  # compss_delete_object(o)
  # compss_barrier()
```

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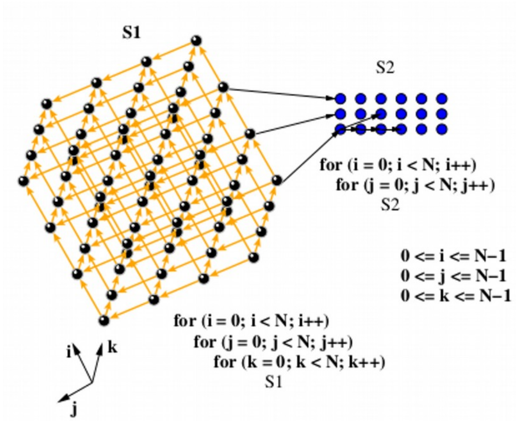
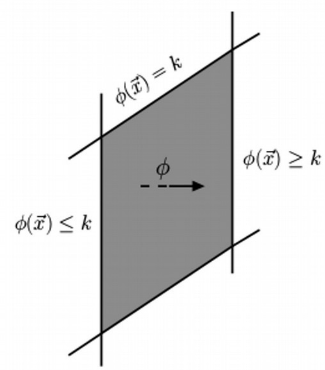
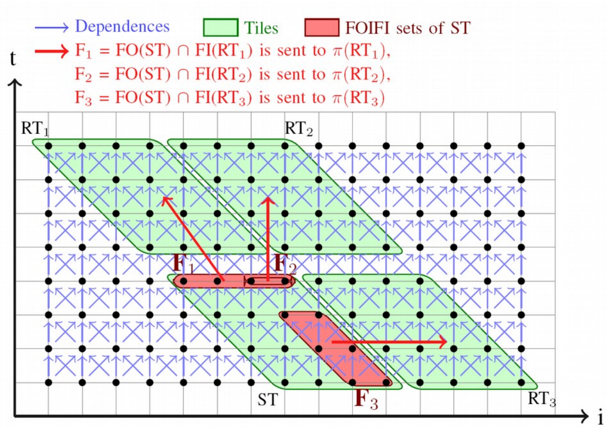
PLUTO

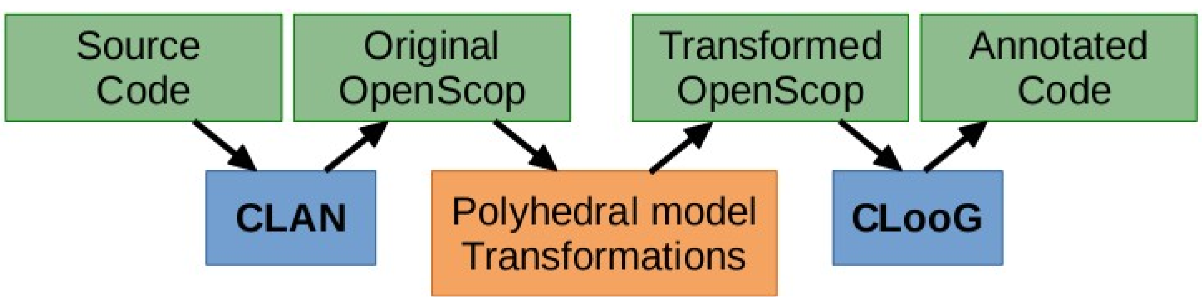
- The **Polyhedral Model** represents the instances of the loop nests' statements as integer points inside a polyhedron







- **PLUTO** is an automatic parallelization tool based on the Polyhedral Model to optimize arbitrarily nested loop sequences with affine dependencies



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AutoParallel

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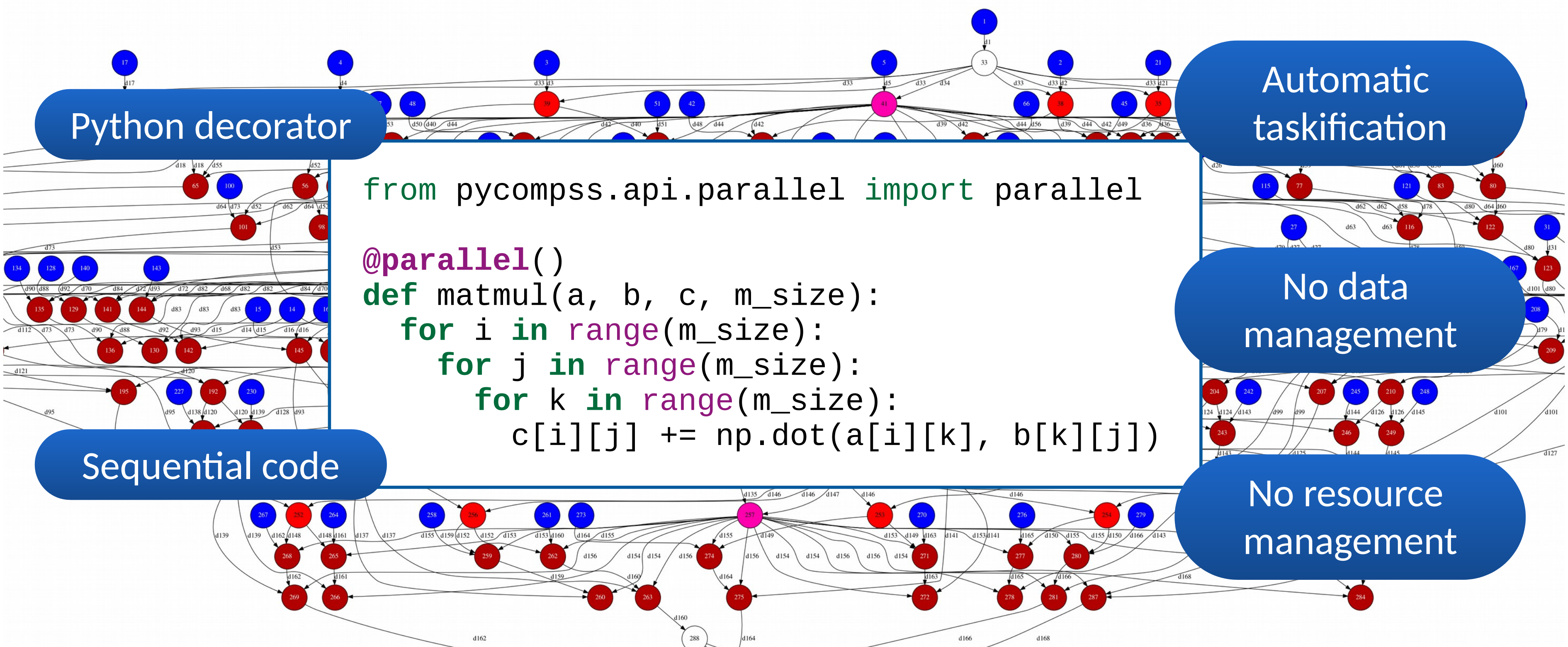
AutoParallel

A single Python decorator to parallelize and distributedly execute sequential code containing affine loop nests



Python decorator

Automatic taskification

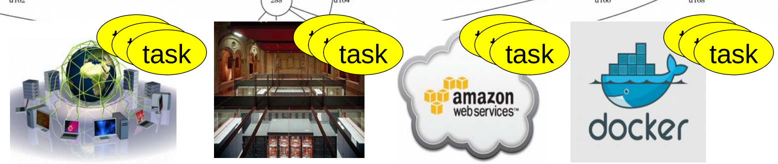
```python
from pycompss.api.parallel import parallel

@parallel()
def matmul(a, b, c, m_size):
  for i in range(m_size):
    for j in range(m_size):
      for k in range(m_size):
        c[i][j] += np.dot(a[i][k], b[k][j])
```

No data management

Sequential code

No resource management



Grid Cluster Cloud Container

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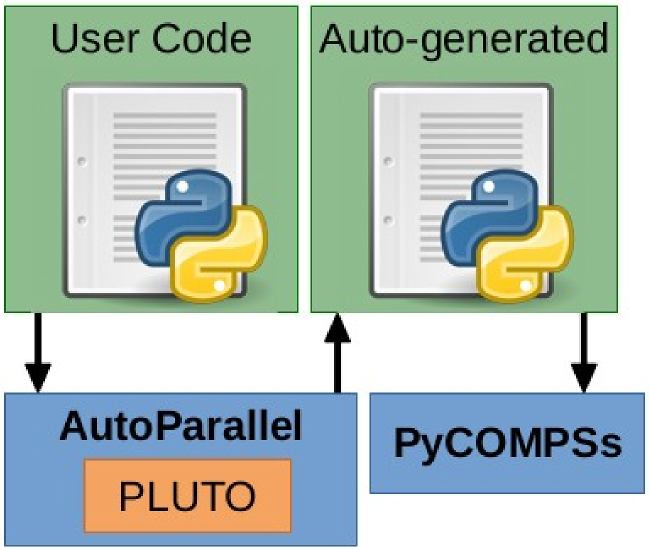
AutoParallel Annotation

- Taskification of affine loop nests at runtime

```
@parallel()
def matmul(a, b, c, m_size):
  for i in range(m_size):
    for j in range(m_size):
      for k in range(m_size):
        c[i][j] += np.dot(a[i][k], b[k][j])
```

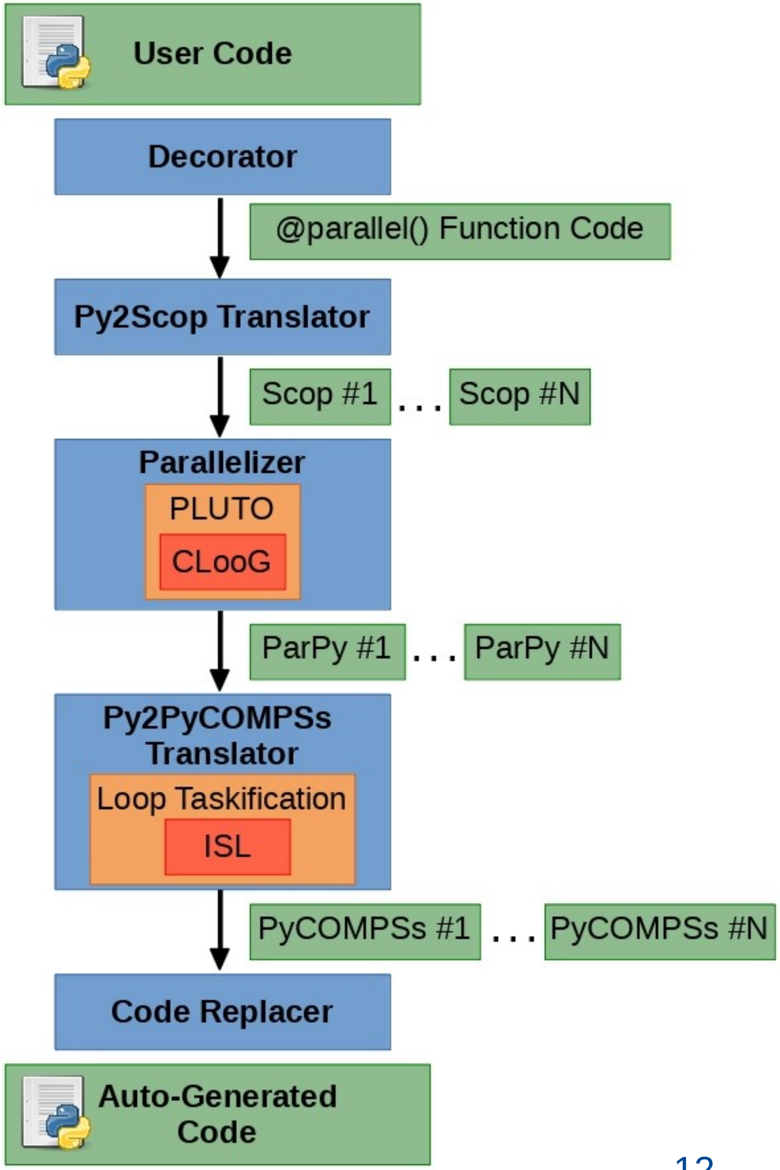



```
# [COMPSs AutoParallel] Begin Autogenerated code
@task(var2=IN, var3=IN, var1=INOUT)
def S1(var2, var3, var1):
  var1 += np.dot(var2, var3)

def matmul(a, b, c, m):
  if m >= 1:
    for t1 in range(0, m - 1): #i
      lbp = 0
      ubp = m - 1
      for t2 in range(lbp, ubp + 1): #k
        lbv = 0
        ubv = m - 1
        for t3 in range(lbv, ubv + 1): #j
          S1(a[t1][t2], b[t2][t3], c[t1][t3])
  compss_barrier()
# [COMPSs AutoParallel] End Autogenerated code
```

AutoParallel Architecture

- Decorator
  - Implements the @parallel decorator
- Python to OpenScop translator
  - Builds a Python Scop object from the Python's AST representing each affine loop nest detected in the user function
- Parallelizer
  - Parallelizes an OpenScop file and returns its Python code using OpenMP syntax
- Python to PyCOMPSs translator
  - Inserts the PyCOMPSs syntax (task annotations and data synchronizations) to the annotated Python code (uses Python's AST)
- Code replacer
  - Replaces each loop nest in the initial user code by the auto-generated code



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Evaluation

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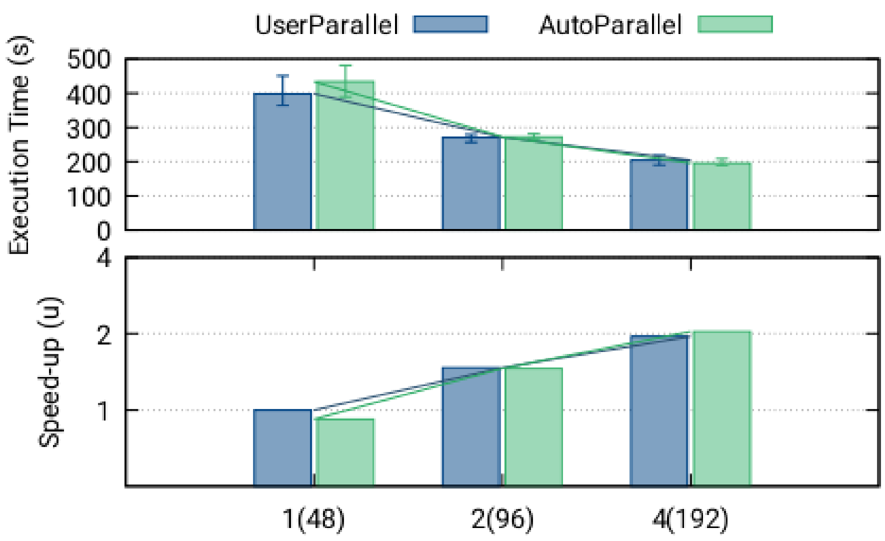
Cholesky

	Code Analysis		
	LoC	*CC*	*NPath*
User	220	26	112
Auto	274	36	14.576

LoC	Lines Of Code
CC	Cyclomatic Complexity
NPath	Npath Complexity

	Loop Analysis		
	#Main	*#Total*	*Depth*
User	1	4	3
Auto	3	9	3



	Problem Size			Execution		
	Total Matrix Size	*#Blocks*	*Block Size*	*Task Types*	*#Tasks*	*SpeedUp @ 192 cores*
User	65.536 x 65.536	32 x 32	2048 x 2048	3	6.512	1,95
Auto				4	7.008	2,04

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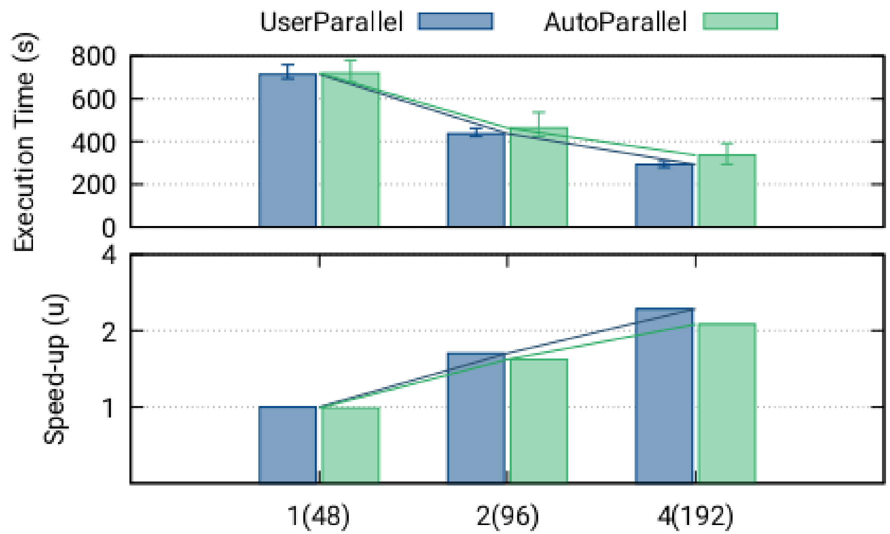
LU

	Code Analysis		
	LoC	***CC***	***NPath***
User	238	35	79.872
Auto	320	39	331.776

	Loop Analysis		
	#Main	***#Total***	***Depth***
User	2	6	3
Auto	2	6	3

LoC Lines Of Code
CC Cyclomatic Complexity
NPath Npath Complexity



	Problem Size			Execution		
	Total Matrix Size	***#Blocks***	***Block Size***	***Task Types***	***#Tasks***	***SpeedUp @ 192 cores***
User	49.152 x 49.152	24 x 24	2048 x 2048	4	14.676	2,45
Auto				12	15.227	2,13

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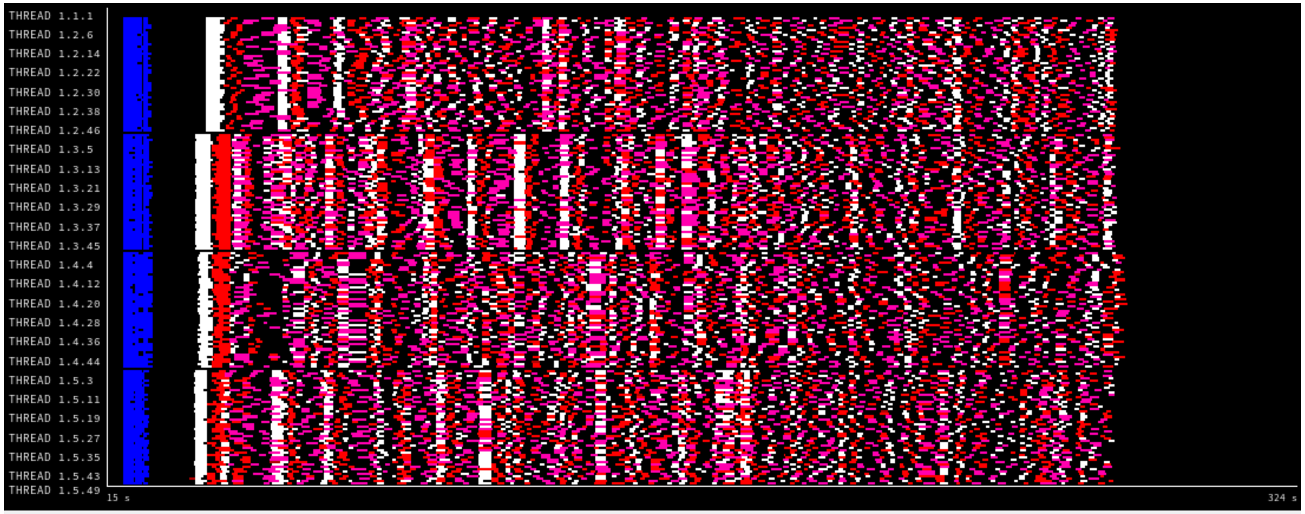
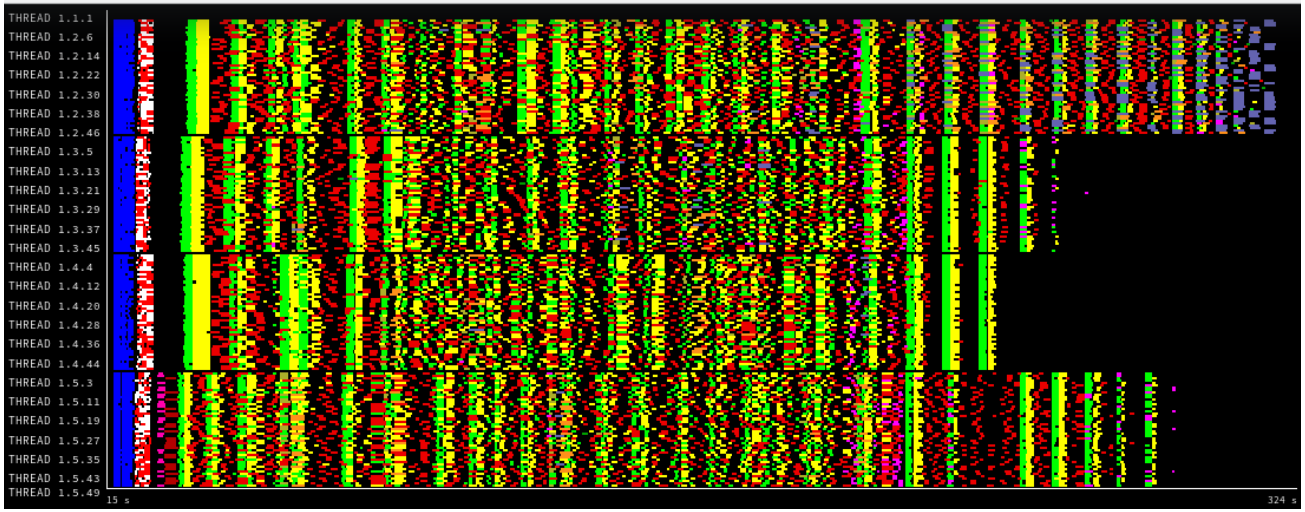
LU

- In-depth performance analysis
  - Paraver trace with 4 workers (192 cores)

UserParallel



AutoParallel

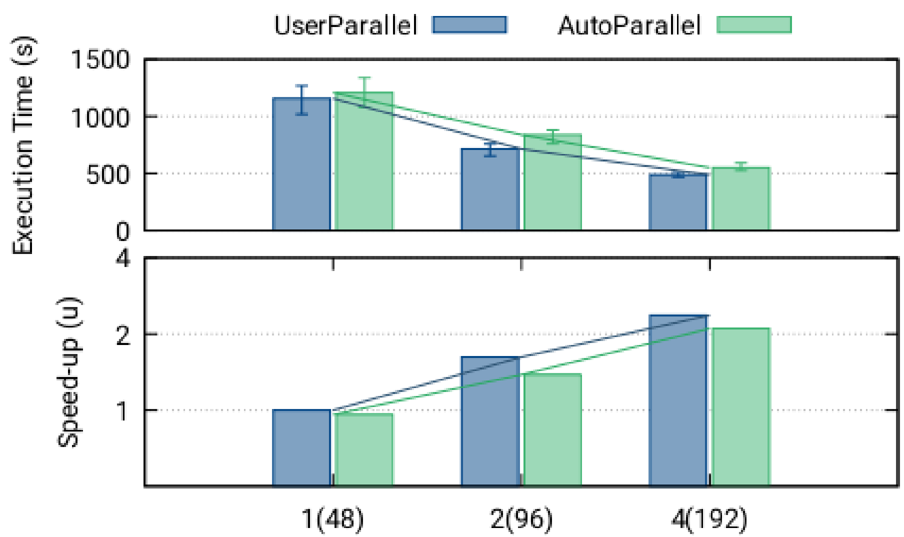


QR

LoC	Lines Of Code
CC	Cyclomatic Complexity
NPath	Npath Complexity

	Code Analysis		
	LoC	*CC*	*NPath*
User	303	41	168
Auto	406	43	344

	Loop Analysis		
	#Main	*#Total*	*Depth*
User	1	6	3
Auto	2	7	3



	Problem Size			Execution		
	Total Matrix Size	*#Blocks*	*Block Size*	*Task Types*	*#Tasks*	*SpeedUp @ 192 cores*
User	32.768 x 32.768	16 x 16	2048 x 2048	4	19.984	2,37
Auto				20	26.304	2,10

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Conclusions and Future Work

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Conclusions and Future Work

- **AutoParallel goes one step further in easing the development of distributed applications**
  - It is a Python module to automatically parallelize affine loop nests and execute them in distributed infrastructures
  - The evaluation shows that the automatically generated codes for the Cholesky, LU, and QR applications can achieve the same performance than the manually parallelized versions

- **Next steps**
  - Loop taskification: An automatic way to create blocks from sequential applications based on loop tiles. Requires:
    - Research on how to simplify the chunk accesses from the AutoParallel module
    - Extend PyCOMPSs to support collection objects (e.g., lists)
  - Integration with different tools similar to PLUTO to support a larger scop of loop nests (e.g., APOLLO)

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EXCELENCIA SEVERO OCHOA

Thank you

cristianrcv/pycompss-autoparallel

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