МИНИСТЕРСТВО НАУКИ И ВЫСШЕГО ОБРАЗОВАНИЯ РОССИЙСКОЙ ФЕДЕРАЦИИ

ФЕДЕРАЛЬНОЕ ГОСУДАРСТВЕННОЕ АВТОНОМНОЕ ОБРАЗОВАТЕЛЬНОЕ УЧРЕЖДЕНИЕ ВЫСШЕГО ОБРАЗОВАНИЯ

НОВОСИБИРСКИЙ НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ

Факультет информационных технологий

Кафедра параллельных вычислений

ОТЧЕТ

О ВЫПОЛНЕНИИ ЛАБОРАТОРНОЙ РАБОТЫ 2

студента x

Новосибирск, 2022

Цель

Научиться векторизовать простые программы численного моделирования

Задание

Решение волнового уравнения методом конечных объёмов. В качестве типов данных нужно использовать double.

Алгоритм моделирует распространение волны в двумерной области, инициированной импульсом из заданного узла сетки. В начальный момент времени значения искомой функции U на сетке инициализируются нулями. На каждом шаге моделирования значения искомой функции пересчитываются по заданной формуле.

Входные данные: **Nx=Ny=10000, Nt=120**.

Процессор: Intel(R) Xeon(R) Gold 6128 CPU @ 3.40GHz

Ход работы

Времена замеров

Оптимизации	Время, сек
Лабораторная 1	48,3
Векторизация компилятора	46,4
OpenMP	40
AVX2	18,9
AVX512	16,7

Выводы:

1. Ручная векторизация дает больший прирост производительности, но требует много времени и делает код архитектурно-зависимым.
2. Компилятор не может эффективно векторизовать участок кода со сложными связями внутри.

Характеристика варианта с OpenMP

Elapsed Time: 59.244s

IPC:	3.397
SP GFLOPS:	0.000
DP GFLOPS:	4.468
x87 GFLOPS:	0.000
Average CPU Frequency:	3.7 GHz

Logical Core Utilization: 3.6% (0.876 out of 24)

Microarchitecture Usage: 82.0% of Pipeline Slots

Retiring:	82.0%	of Pipeline Slots
Front-End Bound:	0.7%	of Pipeline Slots
Bad Speculation:	0.1%	of Pipeline Slots
Back-End Bound:	**17.1%**	**of Pipeline Slots**
Memory Bound:	**3.6%**	**of Pipeline Slots**
L1 Bound:	**0.7%**	**of Clockticks**
L2 Bound:	1.3%	of Clockticks
L3 Bound:	**0.2%**	**of Clockticks**
DRAM Bound:	**1.1%**	**of Clockticks**
Store Bound:	0.9%	of Clockticks
Core Bound:	13.5%	of Pipeline Slots

Memory Bound: 3.6% of Pipeline Slots

Vectorization: 0.0% of Packed FP Operations

Instruction Mix:

SP FLOPs:	0.0%	of uOps
DP FLOPs:	42.2%	of uOps
Packed:	0.0%	from DP FP
Scalar:	100.0%	from DP FP
x87 FLOPs:	0.0%	of uOps
Non-FP:	57.8%	of uOps
FP Arith/Mem Rd Instr. Ratio:	1.249	
FP Arith/Mem Wr Instr. Ratio:	17.053	

Характеристика варианта с AVX2

Elapsed Time: 33.689s

IPC:	2.615
SP GFLOPS:	0.000
DP GFLOPS:	8.156
x87 GFLOPS:	0.179
Average CPU Frequency:	3.6 GHz

Logical Core Utilization: 3.3% (0.792 out of 24)

Microarchitecture Usage: 73.2% of Pipeline Slots

Retiring:	73.2%	of Pipeline Slots
Front-End Bound:	1.4%	of Pipeline Slots
Bad Speculation:	0.3%	of Pipeline Slots
Back-End Bound:	**25.0%**	**of Pipeline Slots**
Memory Bound:	**14.8%**	**of Pipeline Slots**
L1 Bound:	**1.8%**	**of Clockticks**
L2 Bound:	11.0%	of Clockticks
L3 Bound:	**0.2%**	**of Clockticks**
DRAM Bound:	**5.0%**	**of Clockticks**
Store Bound:	1.7%	of Clockticks
Core Bound:	10.2%	of Pipeline Slots

Memory Bound: 14.8% of Pipeline Slots

Vectorization: 91.9% of Packed FP Operations

Instruction Mix:

SP FLOPs:	0.0%	of uOps
DP FLOPs:	24.5%	of uOps
Packed:	100.0%	from DP FP
128-bit:	0.0%	from DP FP
256-bit:	100.0%	from DP FP
512-bit:	0.0%	from DP FP
Scalar:	0.0%	from DP FP
x87 FLOPs:	2.1%	of uOps
Non-FP:	73.4%	of uOps
FP Arith/Mem Rd Instr. Ratio:	1.727	
FP Arith/Mem Wr Instr. Ratio:	3.021	

Характеристика варианта с AVX512

Elapsed Time: 31.781s

IPC:	1.639
SP GFLOPS:	0.000
DP GFLOPS:	8.684
x87 GFLOPS:	0.094
Average CPU Frequency:	3.5 GHz

Logical Core Utilization: 3.2% (0.769 out of 24)

Microarchitecture Usage: 45.0% of Pipeline Slots

Retiring:	45.0%	of Pipeline Slots
Front-End Bound:	2.0%	of Pipeline Slots
Bad Speculation:	0.2%	of Pipeline Slots
Back-End Bound:	**52.9%**	**of Pipeline Slots**
Memory Bound:	**33.9%**	**of Pipeline Slots**
L1 Bound:	**1.1%**	**of Clockticks**
L2 Bound:	13.4%	of Clockticks
L3 Bound:	**0.7%**	**of Clockticks**
DRAM Bound:	**21.8%**	**of Clockticks**
Memory Bandwidth:	73.4%	of Clockticks
Memory Latency:	**11.0%**	**of Clockticks**
Local DRAM:	47.8%	of Clockticks
Remote DRAM:	0.0%	of Clockticks
Remote Cache:	0.0%	of Clockticks
Store Bound:	1.7%	of Clockticks
Core Bound:	19.0%	of Pipeline Slots

Memory Bound: 33.9% of Pipeline Slots

Vectorization: 92.0% of Packed FP Operations

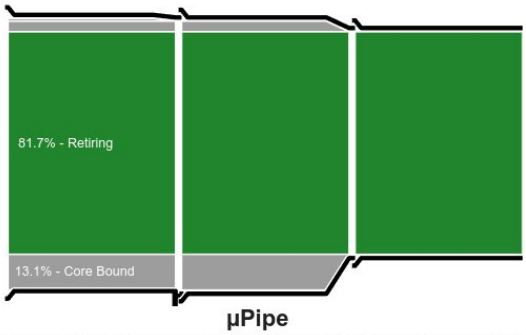
Instruction Mix:

SP FLOPs:	0.0%	of uOps
DP FLOPs:	22.4%	of uOps
x87 FLOPs:	1.9%	of uOps
Non-FP:	75.7%	of uOps
FP Arith/Mem Rd Instr. Ratio:	1.314	
FP Arith/Mem Wr Instr. Ratio:	3.879	

Ограничения варианта с OpenMP

Elapsed Time: 59.289s

Clockticks:	190,706,000,000	
Instructions Retired:	650,335,000,000	
CPI Rate:	0.293	
Retiring:	81.7%	of Pipeline Slots
Light Operations:	81.8%	of Pipeline Slots
FP Arithmetic:	42.1%	of uOps
FP x87:	0.0%	of uOps
FP Scalar:	42.1%	of uOps
FP Vector:	0.0%	of uOps
Memory Operations:	29.4%	of Pipeline Slots
Fused Instructions:	3.4%	of Pipeline Slots
Non Fused Branches:	1.9%	of Pipeline Slots
Nop Instructions:	0.1%	of Pipeline Slots
Other:	4.9%	of Pipeline Slots
Heavy Operations:	0.0%	of Pipeline Slots
Front-End Bound:	0.9%	of Pipeline Slots
Bad Speculation:	0.4%	of Pipeline Slots
Back-End Bound:	17.0%	of Pipeline Slots
Memory Bound:	3.9%	of Pipeline Slots
Core Bound:	13.1%	of Pipeline Slots
Divider:	0.0%	of Clockticks
Port Utilization:	15.3%	of Clockticks
Cycles of 0 Ports Utilized:	2.9%	of Clockticks
Cycles of 1 Port Utilized:	1.6%	of Clockticks
Cycles of 2 Ports Utilized:	6.4%	of Clockticks
Cycles of 3+ Ports Utilized:	38.5%	of Clockticks
Vector Capacity Usage (FPU):	12.5%	
Average CPU Frequency:	3.7 GHz	
Total Thread Count:	1	
Paused Time:	0s	



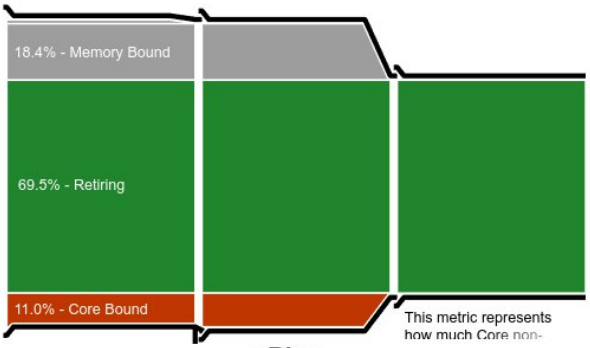
µPipe

This diagram represents inefficiencies in CPU usage. Treat it as a pipe with an output flow equal to the "pipe efficiency" ratio: (Actual Instructions Retired)/(Maximum Possible Instruction Retired). If there are pipeline stalls decreasing the pipe efficiency, the pipe shape gets more narrow.

Ограничения варианта с AVX2

Elapsed Time: 35.337s

Clockticks:	100,351,000,000	
Instructions Retired:	251,005,000,000	
CPI Rate:	0.400	
Retiring:	69.5%	of Pipeline Slots
Front-End Bound:	1.2%	of Pipeline Slots
Bad Speculation:	0.0%	of Pipeline Slots
Back-End Bound:	29.4%	of Pipeline Slots
Memory Bound:	18.4%	of Pipeline Slots
Core Bound:	11.0%	of Pipeline Slots
Divider:	23.7%	of Clockticks
Port Utilization:	9.6%	of Clockticks
Cycles of 0 Ports Utilized:	11.8%	of Clockticks
Cycles of 1 Port Utilized:	1.9%	of Clockticks
Cycles of 2 Ports Utilized:	4.4%	of Clockticks
Cycles of 3+ Ports Utilized:	31.7%	of Clockticks
Vector Capacity Usage (FPU):	46.4%	
Average CPU Frequency:	3.6 GHz	
Total Thread Count:	1	
Paused Time:	0s	



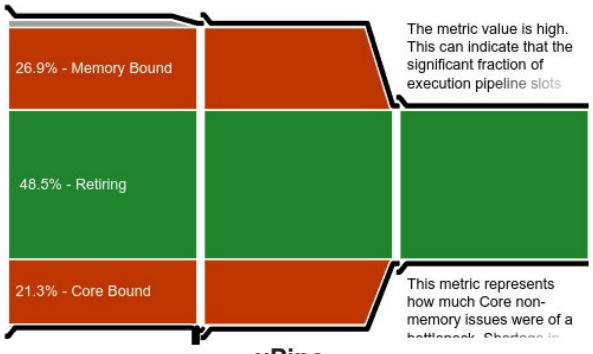
µPipe

This diagram represents inefficiencies in CPU usage. Treat it as a pipe with an output flow equal to the "pipe efficiency" ratio: (Actual Instructions Retired)/(Maximum Possible Instruction Retired). If there are pipeline stalls decreasing the pipe efficiency, the pipe shape gets more narrow.

Ограничения варианта с AVX512

Elapsed Time: 32.379s

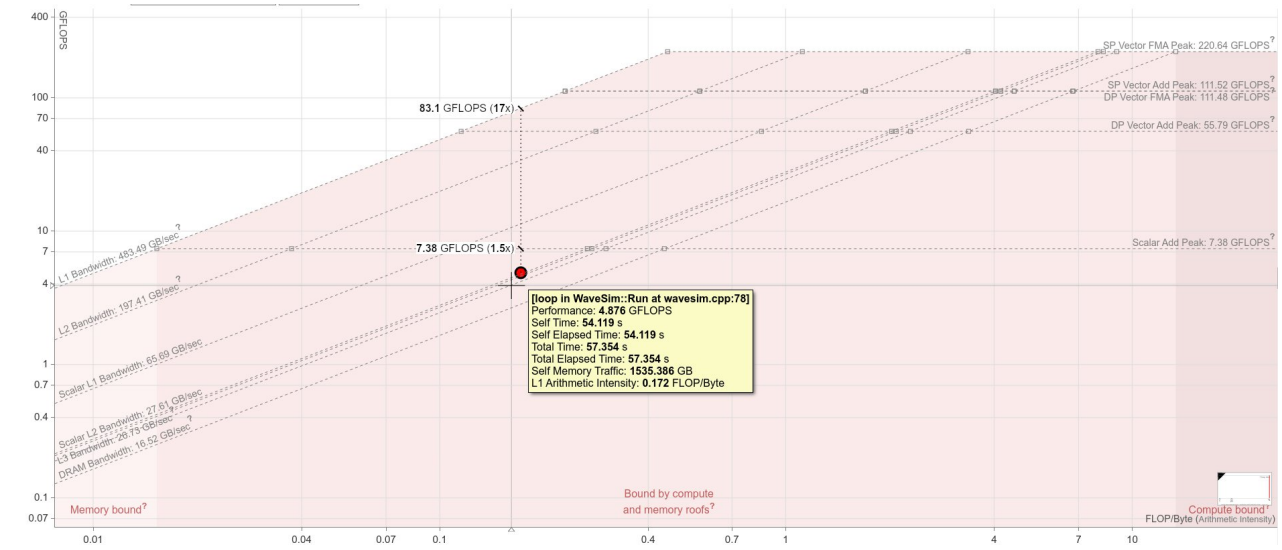
Clockticks:	81,481,000,000	
Instructions Retired:	139,791,000,000	
CPI Rate:	0.583	
Retiring:	48.5%	of Pipeline Slots
Front-End Bound:	2.4%	of Pipeline Slots
Bad Speculation:	1.0%	of Pipeline Slots
Back-End Bound:	48.1%	of Pipeline Slots
Memory Bound:	26.9%	of Pipeline Slots
L1 Bound:	3.7%	of Clockticks
L2 Bound:	14.3%	of Clockticks
L3 Bound:	0.9%	of Clockticks
DRAM Bound:	12.5%	of Clockticks
Memory Bandwidth:	74.5%	of Clockticks
Memory Latency:	9.7%	of Clockticks
Store Bound:	0.9%	of Clockticks
Core Bound:	21.3%	of Pipeline Slots
Divider:	14.4%	of Clockticks
Port Utilization:	22.0%	of Clockticks
Cycles of 0 Ports Utilized:	17.6%	of Clockticks
Cycles of 1 Port Utilized:	6.7%	of Clockticks
Cycles of 2 Ports Utilized:	8.8%	of Clockticks
Cycles of 3+ Ports Utilized:	17.2%	of Clockticks
Vector Capacity Usage (FPU):	93.3%	
Average CPU Frequency:	3.3 GHz	
Total Thread Count:	1	
Paused Time:	0s	



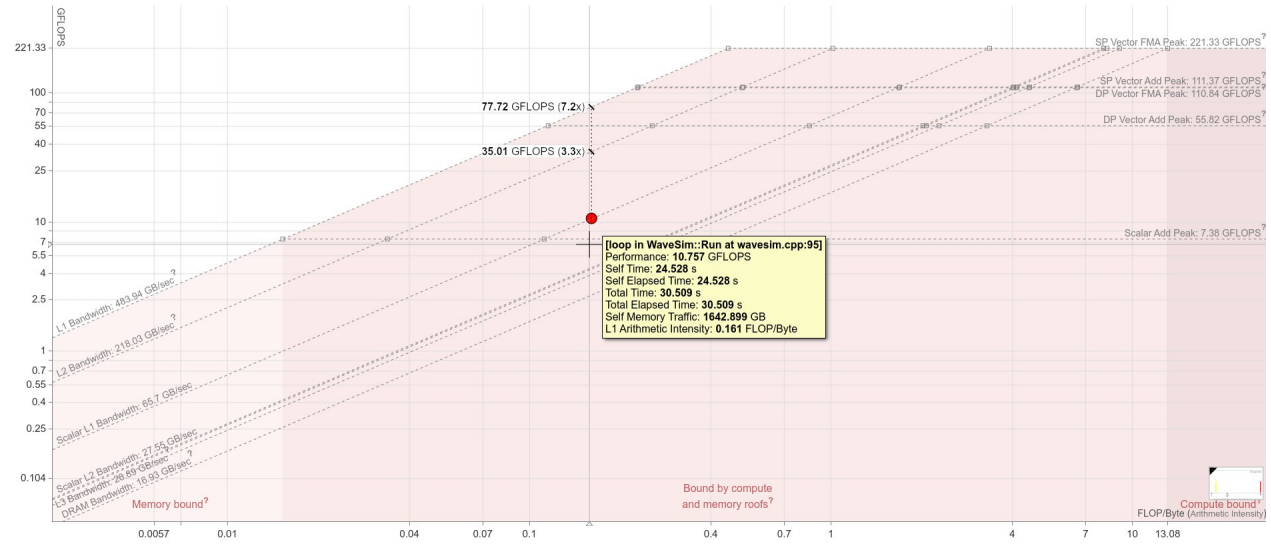
µPipe

This diagram represents inefficiencies in CPU usage. Treat it as a pipe with an output flow equal to the "pipe efficiency" ratio: (Actual Instructions Retired)/(Maximum Possible Instruction Retired). If there are pipeline stalls decreasing the pipe efficiency, the pipe shape gets more narrow.

Roofline варианта с OpenMP



Roofline варианта с AVX2



Roofline варианта с AVX512