COMPILER DESIGN
DIGITAL ASSIGNMENT 3

TEAM MEMBERS:
S.MUKUNTH(22BRS1021)
KAVIN KARTHIK V(22BRS1049)
NANTHAN S NAIR(22BRS1070)

CODES AND THEIR DESCRIPTION:

MATRIX:

```cpp
#include <iostream>
using namespace std;

void multiply(int A[2][2], int B[2][2], int C[2][2]) {
    for (int i = 0; i < 2; i++) {
        for (int j = 0; j < 2; j++) {
            C[i][j] = 0;
            for (int k = 0; k < 2; k++) {
                C[i][j] += A[i][k] * B[k][j];
            }
        }
    }
}

int main() {
    int A[2][2] = {{1, 2}, {3, 4}};
    int B[2][2] = {{5, 6}, {7, 8}};
    int C[2][2];

    multiply(A, B, C);

    cout << "Result Matrix:" << endl;
    for (int i = 0; i < 2; i++) {
        for (int j = 0; j < 2; j++) {
            cout << C[i][j] << " ";
        }
        cout << endl;
    }

    return 0;
}
```

1. Function Definition (‘multiply’):
   - The function `multiply` takes three 2x2 matrices (`A`, `B`, and `C`) as input.
   - It uses three nested loops:
     - The outer loop iterates over rows of matrix `A`.
     - The middle loop iterates over columns of matrix `B`.

- The innermost loop performs the dot product calculation for each element in the resulting matrix.

2. Matrix Initialization:
- In the `main` function, matrices `A` and `B` are initialized with predefined values:

A = {{1, 2}, {3, 4}}
B = {{5, 6}, {7, 8}}
- Matrix `C` is declared to store the result.

3. Output:
- After calling the `multiply` function, the program prints the resulting matrix (`C`) using nested loops.

```
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ clang++ -S -emit-llvm matrix.cpp -o matrix.ll
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ cat matrix.ll
; ModuleID = 'matrix.cpp'
source_filename = "matrix.cpp"
target datalayout = "e-m:e-p270:32:32-p271:32:32-p272:64:64-i64:64-f80:128-n8:16:32:64-S128"
target triple = "x86_64-pc-linux-gnu"

%"class.std::ios_base::Init" = type { i8 }
%"class.std::basic_ostream" = type { i32 (...)**, %"class.std::basic_ios" }
%"class.std::basic_ios" = type { %"class.std::ios_base", %"class.std::basic_ostream"*, i8, i8, %"class.std::basic_streambuf"*, %"class.std::ctype"*, %"class.std::num_put
"*, %"class.std::num_get"* }
%"class.std::ios_base" = type { i32 (...)**, i64, i64, i32, i32, i32, %"struct.std::ios_base::_Callback_list"*, %"struct.std::ios_base::_Words", [8 x %"struct.std::ios_b
ase::_Words"], i32, %"struct.std::ios_base::_Words"*, %"class.std::locale" }
%"struct.std::ios_base::_Callback_list" = type { %"struct.std::ios_base::_Callback_list"*, void (i32, %"class.std::ios_base"*, i32)*, i32, i32 }
%"struct.std::ios_base::_Words" = type { i8*, i64 }
%"class.std::locale" = type { %"class.std::locale::_Impl"* }
%"class.std::locale::_Impl" = type { i32, %"class.std::locale::facet"**, i64, %"class.std::locale::facet"**, i8** }
%"class.std::locale::facet" = type <{ i32 (...)**, i32, [4 x i8] }>
%"class.std::basic_streambuf" = type { i32 (...)**, i8*, i8*, i8*, i8*, i8*, i8*, %"class.std::locale" }
%"class.std::ctype" = type <{ %"class.std::locale::facet.base", [4 x i8], %struct.__locale_struct*, i8, [7 x i8], i32*, i32*, i16*, i8, [256 x i8], [256 x i8], i8, [6 x
i8] }>
%"class.std::locale::facet.base" = type <{ i32 (...)**, i32 }>
%struct.__locale_struct = type { [13 x %struct.__locale_data*], i16*, i32*, i32*, [13 x i8*] }
%struct.__locale_data = type opaque
%"class.std::num_put" = type { %"class.std::locale::facet.base", [4 x i8] }
%"class.std::num_get" = type { %"class.std::locale::facet.base", [4 x i8] }

@_ZStL8__ioinit = internal global %"class.std::ios_base::Init" zeroinitializer, align 1
@__dso_handle = external hidden global i8
@__const.main.A = private unnamed_addr constant [2 x [2 x i32]] [[2 x i32] [i32 1, i32 2], [2 x i32] [i32 3, i32 4]], align 16
@__const.main.B = private unnamed_addr constant [2 x [2 x i32]] [[2 x i32] [i32 5, i32 6], [2 x i32] [i32 7, i32 8]], align 16
@_ZSt4cout = external global %"class.std::basic_ostream", align 8
@.str = private unnamed_addr constant [15 x i8] c"Result Matrix:\00", align 1
```

1. Compilation Command:
- The user runs the command `clang++ -S -emit-llvm matrix.cpp -o matrix.ll`, which compiles the `matrix.cpp` file into LLVM IR. The output is saved in a file named `matrix.ll`.

2. LLVM IR File Content:
- The content of the `matrix.ll` file is displayed using the `cat matrix.ll` command. It contains LLVM IR code generated from the C++ source file.
- The IR includes metadata about the source file (`matrix.cpp`), target architecture (`x86_64-pc-linux-gnu`), and various data structures and global variables.

3. Matrix Data Representation:
The IR defines constants for two matrices (`A` and `B`) initialized with values:

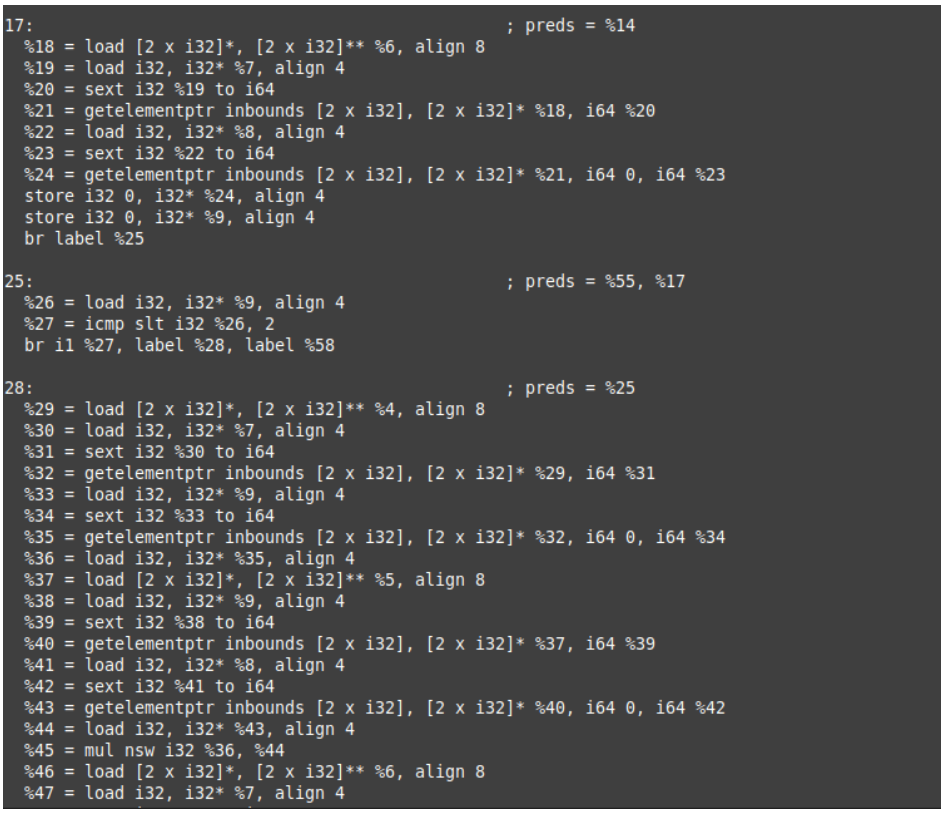
@const.main.A = private unnamed addr constant [2 x [2 x i32]] [[i32 1, i32 2], [i32 3, i32 4]], align 16
@const.main.B = private unnamed addr constant [2 x [2 x i32]] [[i32 5, i32 6], [i32 7, i32 8]], align 16
```
```

- These matrices are likely used for matrix multiplication in the program.

4. Result Matrix String:
   - A string constant `Result Matrix:\00` is defined in the IR, which will be used for displaying output.

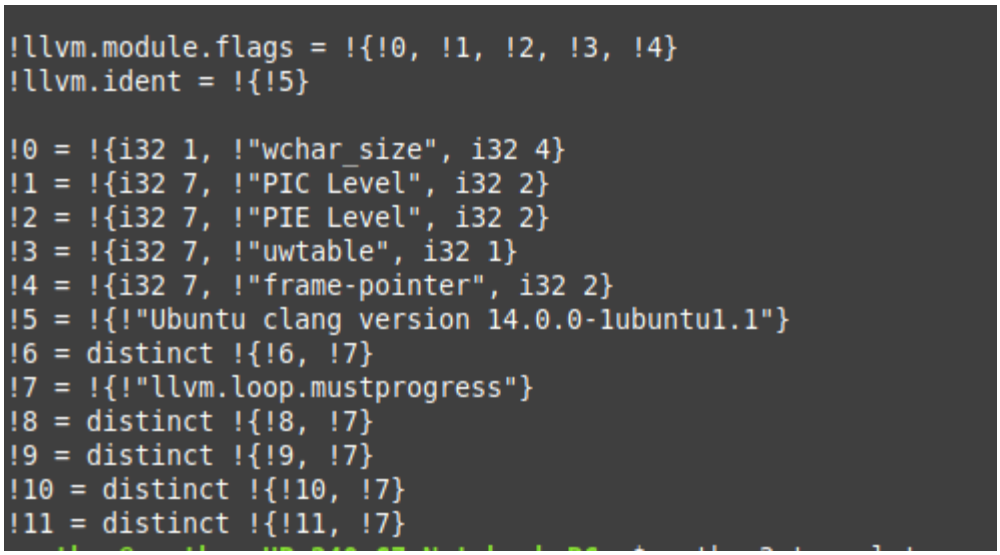
```
; Function Attrs: nounwind
declare void @_ZNSt8ios_base4InitD1Ev(%"class.std::ios_base::Init"* noundef nonnull align 1 dereferenceable(1)) unnamed_addr #2

; Function Attrs: nounwind
declare i32 @__cxa_atexit(void (i8*)*, i8*, i8*) #3

; Function Attrs: mustprogress noinline nounwind optnone uwtable
define dso_local void @_Z8multiplyPA2_iS0_S0_([2 x i32]* noundef %0, [2 x i32]* noundef %1, [2 x i32]* noundef %2) #4 {
  %4 = alloca [2 x i32]*, align 8
  %5 = alloca [2 x i32]*, align 8
  %6 = alloca [2 x i32]*, align 8
  %7 = alloca i32, align 4
  %8 = alloca i32, align 4
  %9 = alloca i32, align 4
  store [2 x i32]* %0, [2 x i32]** %4, align 8
  store [2 x i32]* %1, [2 x i32]** %5, align 8
  store [2 x i32]* %2, [2 x i32]** %6, align 8
  store i32 0, i32* %7, align 4
  br label %10

10:                                               ; preds = %63, %3
  %11 = load i32, i32* %7, align 4
  %12 = icmp slt i32 %11, 2
  br i1 %12, label %13, label %66

13:                                               ; preds = %10
  store i32 0, i32* %8, align 4
  br label %14

14:                                               ; preds = %59, %13
  %15 = load i32, i32* %8, align 4
  %16 = icmp slt i32 %15, 2
  br i1 %16, label %17, label %62

17:                                               ; preds = %14
  %18 = load [2 x i32]*, [2 x i32]** %6, align 8
  %19 = load i32, i32* %7, align 4
  %20 = sext i32 %19 to i64
  %21 = getelementptr inbounds [2 x i32], [2 x i32]* %18, i64 %20
```

This image contains LLVM intermediate representation (IR) code, which is a low-level representation of a program. The code appears to define functions with attributes such as nounwind and optnone, and it includes memory allocations (alloca), pointer manipulations, and control flow (br instructions). Specifically, the function shown in the image processes 2x2 integer matrices, storing and loading values while performing comparisons and branching. The structure suggests that it might be part of a compiled C++ program, potentially implementing matrix multiplication or similar operations.



```
17:                                               ; preds = %14
  %18 = load [2 x i32]*, [2 x i32]** %6, align 8
  %19 = load i32, i32* %7, align 4
  %20 = sext i32 %19 to i64
  %21 = getelementptr inbounds [2 x i32], [2 x i32]* %18, i64 %20
  %22 = load i32, i32* %8, align 4
  %23 = sext i32 %22 to i64
  %24 = getelementptr inbounds [2 x i32], [2 x i32]* %21, i64 0, i64 %23
  store i32 0, i32* %24, align 4
  store i32 0, i32* %9, align 4
  br label %25

25:                                               ; preds = %55, %17
  %26 = load i32, i32* %9, align 4
  %27 = icmp slt i32 %26, 2
  br i1 %27, label %28, label %58

28:                                               ; preds = %25
  %29 = load [2 x i32]*, [2 x i32]** %4, align 8
  %30 = load i32, i32* %7, align 4
  %31 = sext i32 %30 to i64
  %32 = getelementptr inbounds [2 x i32], [2 x i32]* %29, i64 %31
  %33 = load i32, i32* %9, align 4
  %34 = sext i32 %33 to i64
  %35 = getelementptr inbounds [2 x i32], [2 x i32]* %32, i64 0, i64 %34
  %36 = load i32, i32* %35, align 4
  %37 = load [2 x i32]*, [2 x i32]** %5, align 8
  %38 = load i32, i32* %9, align 4
  %39 = sext i32 %38 to i64
  %40 = getelementptr inbounds [2 x i32], [2 x i32]* %37, i64 %39
  %41 = load i32, i32* %8, align 4
  %42 = sext i32 %41 to i64
  %43 = getelementptr inbounds [2 x i32], [2 x i32]* %40, i64 0, i64 %42
  %44 = load i32, i32* %43, align 4
  %45 = mul nsw i32 %36, %44
  %46 = load [2 x i32]*, [2 x i32]** %6, align 8
  %47 = load i32, i32* %7, align 4
```

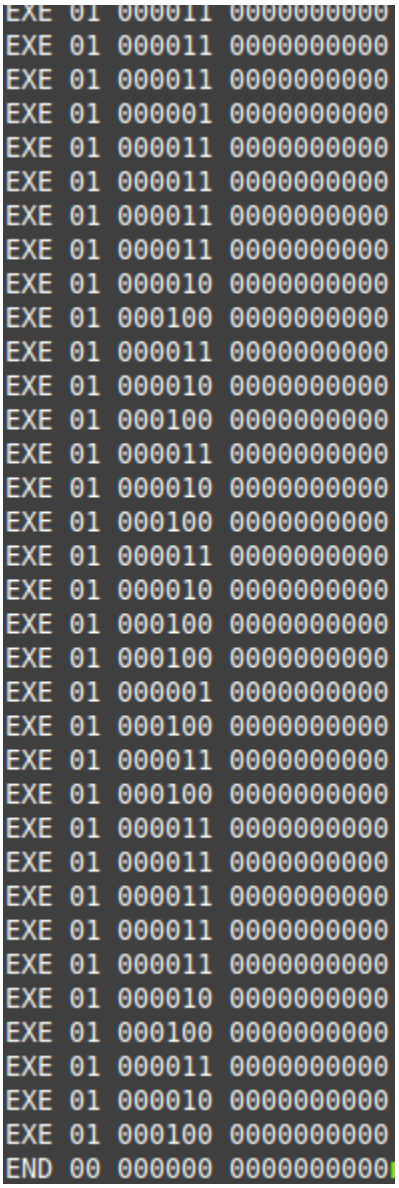
This image displays LLVM IR code, continuing from the previous function. It includes pointer manipulations, integer extensions (sext), and memory access operations (load, store). The code references 2x2 integer arrays and performs index calculations using getelementptr. Additionally, control flow instructions (br) indicate loop execution, likely iterating over matrix elements. The presence of multiple load and store instructions suggests this code is part of a matrix computation, possibly a multiplication or accumulation step in a nested loop.



```
!llvm.module.flags = !{!0, !1, !2, !3, !4}
!llvm.ident = !{!5}

!0 = !{i32 1, !"wchar_size", i32 4}
!1 = !{i32 7, !"PIC Level", i32 2}
!2 = !{i32 7, !"PIE Level", i32 2}
!3 = !{i32 7, !"uwtable", i32 1}
!4 = !{i32 7, !"frame-pointer", i32 2}
!5 = !{!"Ubuntu clang version 14.0.0-1ubuntu1.1"}
!6 = distinct !{!6, !7}
!7 = !{!"llvm.loop.mustprogress"}
!8 = distinct !{!8, !7}
!9 = distinct !{!9, !7}
!10 = distinct !{!10, !7}
!11 = distinct !{!11, !7}
```

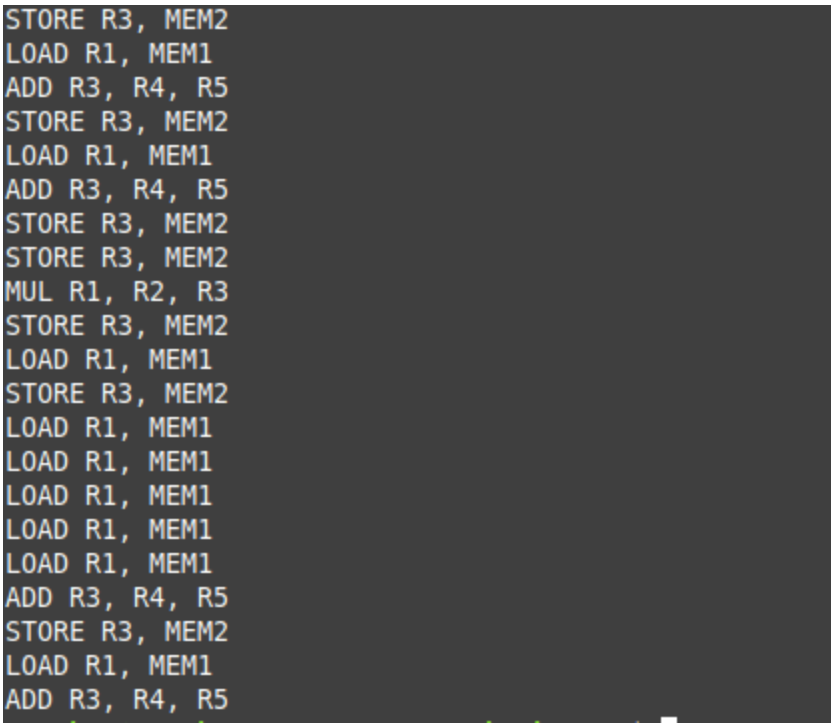
This image shows LLVM metadata, which provides additional information about the compiled program. It includes llvm.module.flags, specifying properties like wchar_size, PIC Level (Position Independent Code), PIE Level (Position Independent Executable), uwtable (unwind table for exception handling), and frame-pointer settings. The llvm.ident metadata identifies the compiler version, in this case, Ubuntu clang version 14.0.0. Additionally, there are distinct metadata nodes related to loop properties, such as llvm.loop.mustprogress, which ensures loop execution is treated as always making progress.

```
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ python3 translate.py
pPIM ISA Generated! Check output_pPIM.isa
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ cat output_pPIM.isa
PROG 10 000000 0000000000
EXE 01 000010 0000000000
EXE 01 000010 0000000000
EXE 01 000010 0000000000
EXE 01 000010 0000000000
EXE 01 000010 0000000000
EXE 01 000010 0000000000
EXE 01 000001 0000000000
EXE 01 000100 0000000000
EXE 01 000100 0000000000
EXE 01 000100 0000000000
EXE 01 000100 0000000000
EXE 01 000011 0000000000
EXE 01 000100 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000100 0000000000
EXE 01 000100 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000001 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
EXE 01 000011 0000000000
```



This image shows a terminal session where a Python script (translate.py) is executed to generate pPIM ISA (Instruction Set Architecture) code. The output file (output_pPIM.isa) is then displayed using the cat command. The file contains a sequence of instructions, each starting with EXE, followed by binary-encoded operation codes. The program appears to involve a repetitive execution pattern, likely related to a simple computation or testing routine for the pPIM architecture. The structured format suggests that this might be an intermediate step in compiling or simulating low-level instructions.

```
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ nano trans.py
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ python3 trans.py
Custom ISA Generated! Check output.isa
nanthan@nanthan-HP-240-G7-Notebook-PC:~$ cat output.isa
ADD R3, R4, R5
ADD R3, R4, R5
ADD R3, R4, R5
ADD R3, R4, R5
ADD R3, R4, R5
ADD R3, R4, R5
MUL R1, R2, R3
STORE R3, MEM2
STORE R3, MEM2
STORE R3, MEM2
STORE R3, MEM2
LOAD R1, MEM1
STORE R3, MEM2
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
STORE R3, MEM2
STORE R3, MEM2
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
MUL R1, R2, R3
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
LOAD R1, MEM1
ADD R3, R4, R5
STORE R3, MEM2
```



The LOAD instruction retrieves a value from a specified memory location (e.g., MEM1) and stores it into a register (e.g., R1), enabling data transfer from memory to CPU for processing. The STORE instruction does the reverse, writing the value from a register (e.g., R3) into a designated memory address (e.g., MEM2), ensuring data persistence. The ADD instruction performs arithmetic addition between two source registers (e.g., R4 and R5), storing the result in a destination register (e.g., R3). This sequence allows data movement (LOAD), computation (ADD), and storage (STORE), forming the fundamental operations of a basic program execution cycle.

UPDATED PROGRESS

1) REFINED pPIM ISA OUTPUT

```
nanthan@nanthan-HP-240-G7-Notebook-PC:~/Desktop/matr
PROG 10 000000 0000000000
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
CMP 01 000101 0000000000 ; Compare less than
CTRL 01 000110 0000000000 ; Conditional branch
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
CMP 01 000101 0000000000 ; Compare less than
CTRL 01 000110 0000000000 ; Conditional branch
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
CMP 01 000101 0000000000 ; Compare less than
CTRL 01 000110 0000000000 ; Conditional branch
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000001 0000000000 ; Multiplication
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
```

```
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000010 0000000000 ; Addition
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000010 0000000000 ; Addition
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000010 0000000000 ; Addition
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000010 0000000000 ; Addition
MEM 01 000100 0000000000 ; Store to memory
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 001001 0000000000 ; Memory allocation
MEM 01 000100 0000000000 ; Store to memory
ADDR 01 000111 0000000000 ; Address calculation
ADDR 01 000111 0000000000 ; Address calculation
ADDR 01 000111 0000000000 ; Address calculation
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
CMP 01 000101 0000000000 ; Compare less than
CTRL 01 000110 0000000000 ; Conditional branch
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
CMP 01 000101 0000000000 ; Compare less than
CTRL 01 000110 0000000000 ; Conditional branch
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
ADDR 01 000111 0000000000 ; Address calculation
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000010 0000000000 ; Addition
MEM 01 000100 0000000000 ; Store to memory
MEM 01 000011 0000000000 ; Load from memory
EXE 01 000010 0000000000 ; Addition
MEM 01 000100 0000000000 ; Store to memory
CTRL 01 001000 0000000000 ; Return
END 00 000000 0000000000
```

2) LOOKUP-TABLE

```
nanthan@nanthan-HP-240-G7-Notebook-PC:~/Desktop/matrix_compiler$ python3 look.py matrix_opt.ll
Lookup Table:
add             -> ADD
sub             -> SUB
mul             -> MUL
load            -> LD
store           -> ST
icmp            -> CMP
br              -> BR
getelementptr   -> GEP
sext            -> SEXT
trunc           -> TRUNC
phi             -> PHI
```

3) PYTHON STREAMLIT FRONT-END OUTPUT

Matrix Processing & pPIM ISA Generator

Upload C++ File

Drag and drop file here

Limit 200MB per file • CPP

Browse files

matrix.cpp 0.6KB

Uploaded: matrix.cpp

Three Address Code (TAC)

TAC Output

```
t0 = A[i][k] * B[k][j]
C[i][j] = C[i][j] + t0
```

Lookup Table (LUT)

LUT Output

```
Operation Frequency:
*: 1
+: 1

Lookup Table:
add         -> ADD
sub         -> SUB
mul         -> MUL
```

pPIM ISA Translation

pPIM ISA Output

```
PROG 10 000000 0000000000
EXE  01 000000 0000000000
LD R1, [A]
LD R1, [A]
MUL R1, R2, R3
ADD R4, R3, R5
ST R5, [C]
END  11 111111 0000000000
```