C Language Support in OSCAR Multigrain Parallelizing Compiler using CoSy

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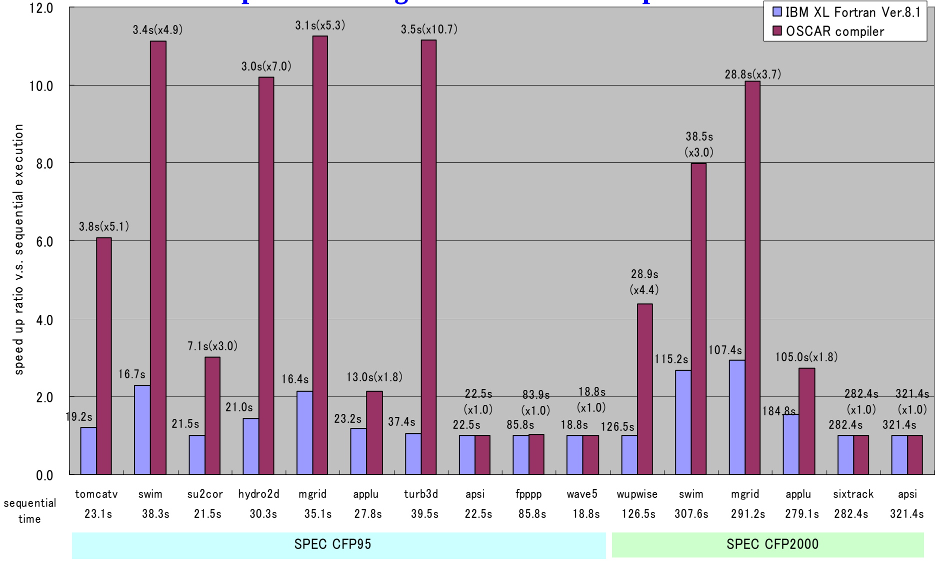
Research Background

- **Multi-Processors and Multi-Cores are emerging everywhere**
- **Automatic parallelizing compiler becomes more and more important**
  - For ease of application development
- **OSCAR Multigrain Parallelizing Compiler**
  - Originally started from FORTRAN77
  - Achieving outstanding results for numerical applications

Performance Evaluation Results

on 16 processor high-end server IBM pSeries 690

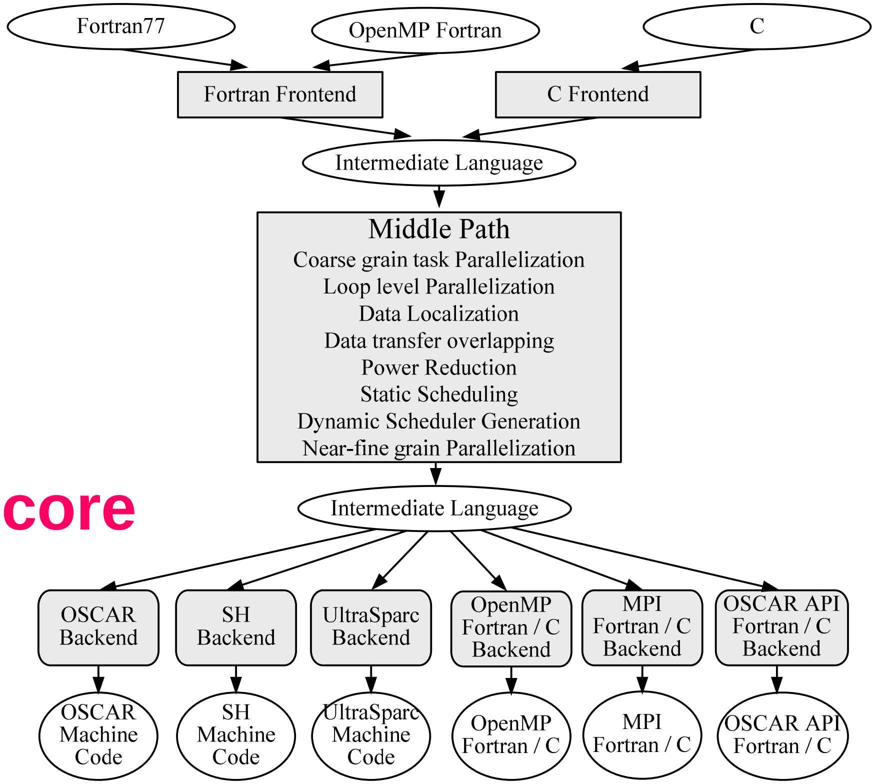


average 3.5 times, max 10.7 times speed up against IBM XL Fortran Ver.8.1

  - Strong demands for supporting C language
    - Very popular especially in embedded area

OSCAR Multigrain Parallelizing Compiler

- *Generating a parallelized code from a sequential program*



Fortran77

OpenMP Fortran

C

Fortran Frontend

C Frontend

Intermediate Language

Middle Path
Coarse grain task Parallelization
Loop level Parallelization
Data Localization
Data transfer overlapping
Power Reduction
Static Scheduling
Dynamic Scheduler Generation
Near-fine grain Parallelization

Intermediate Language

OSCAR Backend

SH Backend

UltraSparc Backend

OpenMP Fortran / C Backend

MPI Fortran / C Backend

OSCAR API Fortran / C Backend

OSCAR Machine Code

SH Machine Code

UltraSparc Machine Code

OpenMP Fortran / C

MPI Fortran / C

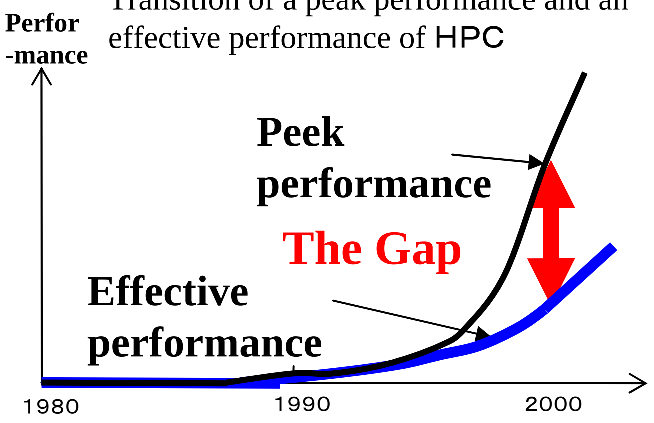
OSCAR API Fortran / C

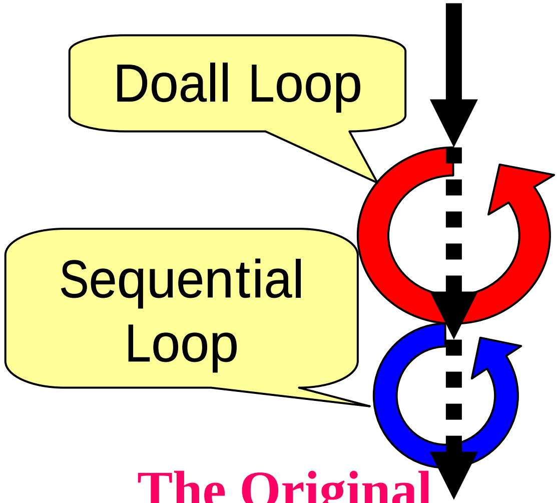
- **Features**
  - **Multigrain Parallel Processing**
  - **Data Localization**
  - **Data transfer Overlapping**
  - **Power Reduction**
- **Compiler cooperative Multi-core architecture**
  - OSCAR Multi-core Architecture
  - OSCAR Heterogeneous Multiprocessor Architecture
- **Also targeting commercial machines**
  - Sun Ultra80, IBM p550Q, SGI Altix 350
  - NEC ARM MPCore, Fujitsu FR1000, Hitachi Renesas SH Multi-core

Multi-grain Parallel Processing

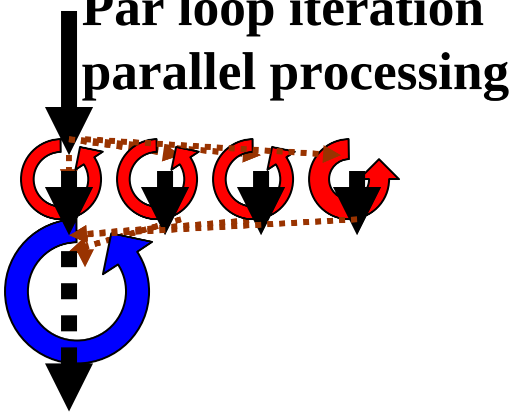
- **Limitation of Loop level Parallelism**
  - Popular parallelizing technique
  - Already reached maturity
- **Exploitation of three kinds of parallelism**
  - Coarse grain task : subroutines, loops, basic blocks
  - Loop level : iterations in a loop
  - Near-fine grain : statements in a basic block

Transition of a peak performance and an effective performance of HPC

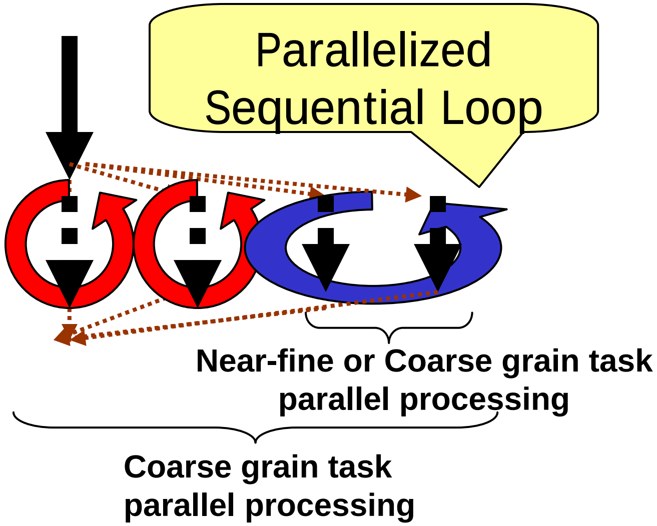




The Original Sequential Program



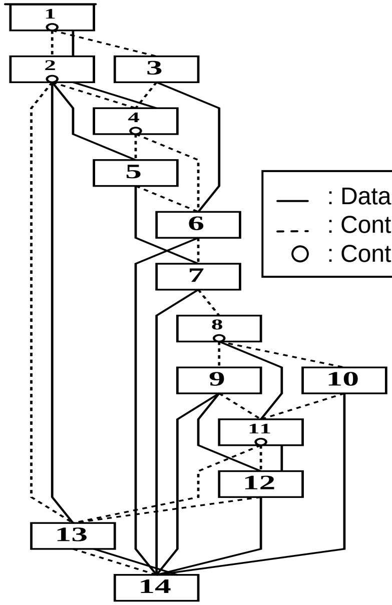
Parallel Processing by an Ordinary Parallelizing Compiler


Parallelized Sequential Loop
Near-fine or Coarse grain task parallel processing
Coarse grain task parallel processing

Multigrain Parallel Processing by OSCAR Compiler

Coarse grain task Parallel Processing

- **A program is decomposed into Macro-Tasks (MTs)**
  - Block of Pseudo Assignments (BPA) : Basic Block (BB)
  - Repetition Block (RB) : natural loop
  - Subroutine Block (SB) : subroutine
- **Exploitation of parallelism**
  - Macro-Flow Graph (MFG) : control-flows and data-dependencies
  - Macro-Task Graph (MTG) : coarse grain task parallelism



Macro-Flow Graph

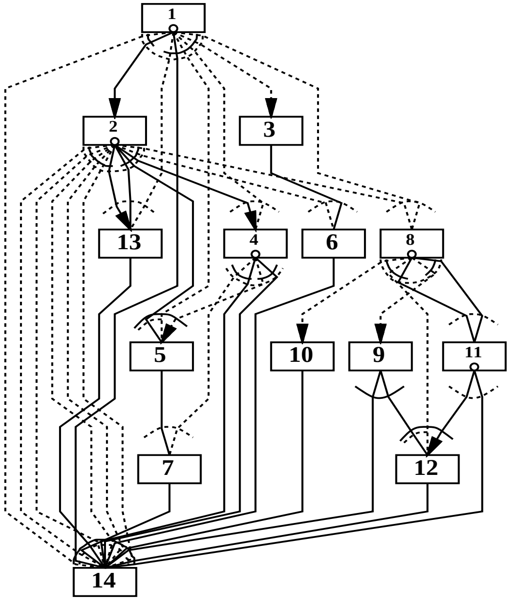
— : Data Dependency
- - - : Control flow
○ : Control Branch

Earliest Executable Condition (EEC)

(Condition for determination of MT Execution)
AND
(Condition for Data access)

Ex. Earliest Executable
Condition of MT6

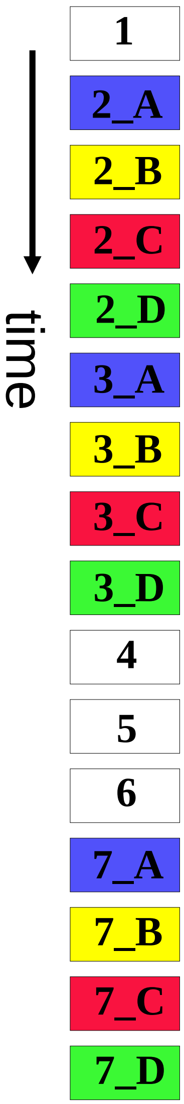
MT2 takes a branch
that guarantees MT4 will be executed
OR
MT3 completes execution



Macro-Task Graph

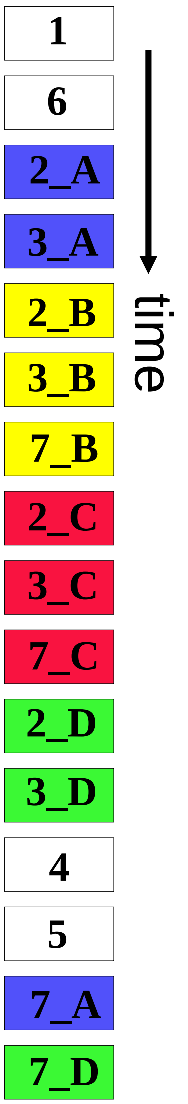
Data Localization

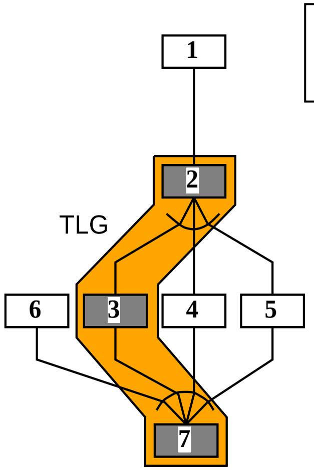
Original execution order on single processor



- **Exploitation of Data Locality**
  - for effective use of faster memory (cache or local memory)
- **Loop Aligned Decomposition (LAD)**
  - Target loops are divided into partial loops considering access range and local memory size
- **Consecutive MT scheduling**
  - Assigning MTs in a DLG to the same processor as consecutive as possible
  - Shared data can be passed through processor local memory

Scheduled result on single processor



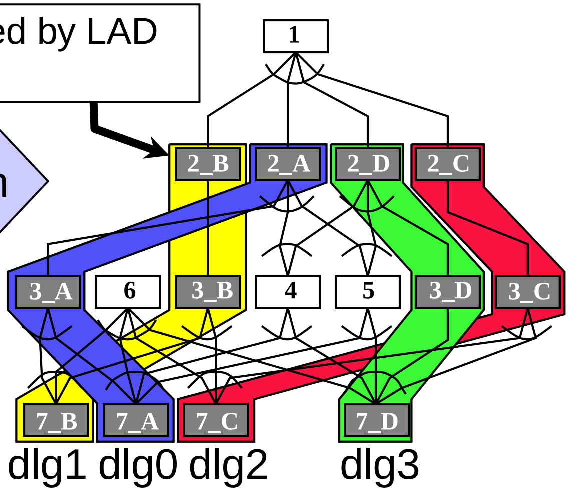


(a) Before loop decomposition

Loop Align Decomposition

Loops 2,3,7 are divided into 4 smaller loops respectively

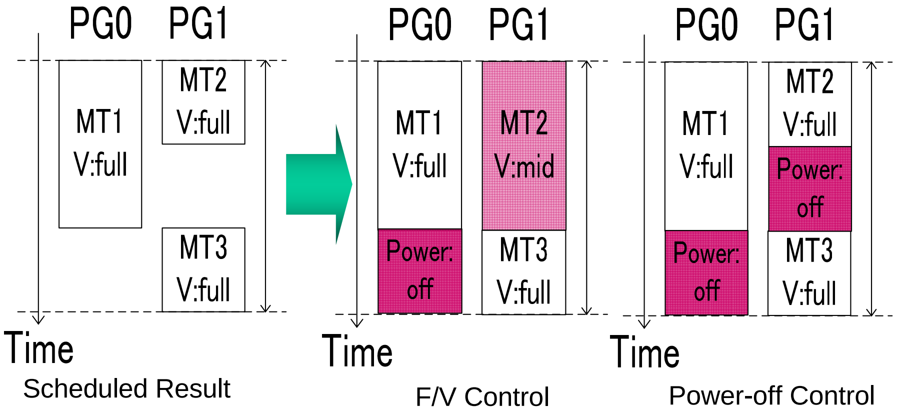
•Gray macro-tasks are generated by LAD
•Colored bands show DLG



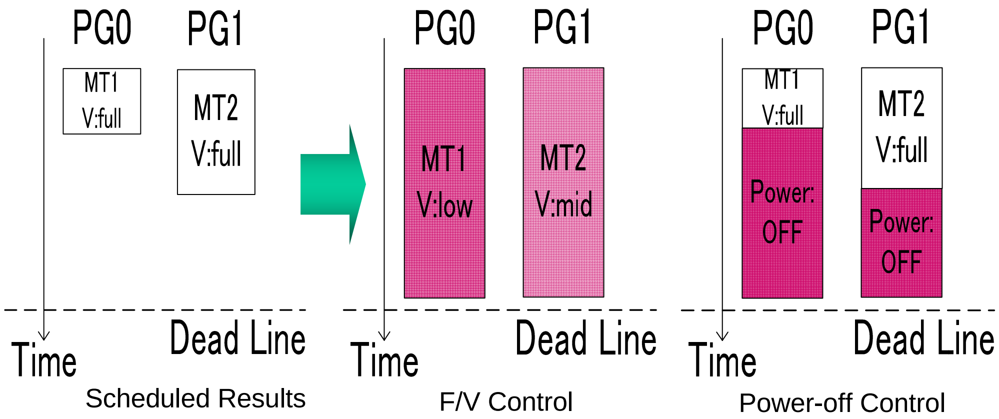
(b) after loop decomposition

Power Reduction

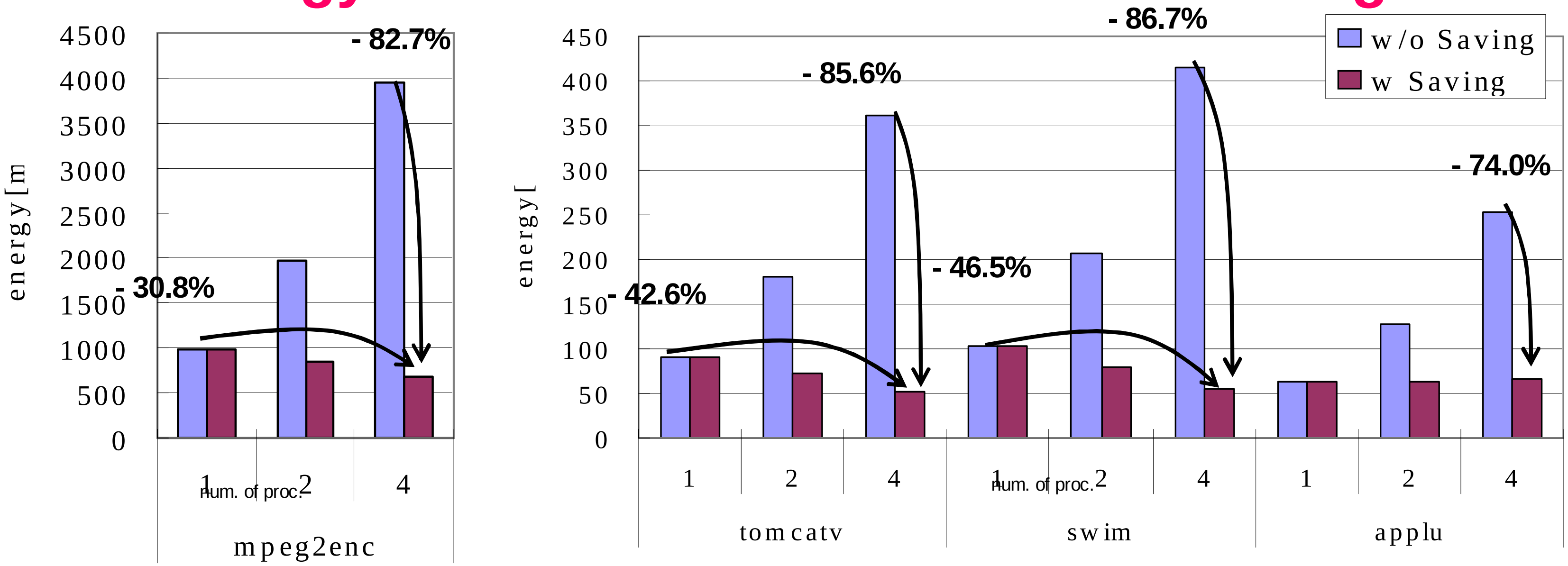
Fastest Execution Mode



Real-time Execution Mode

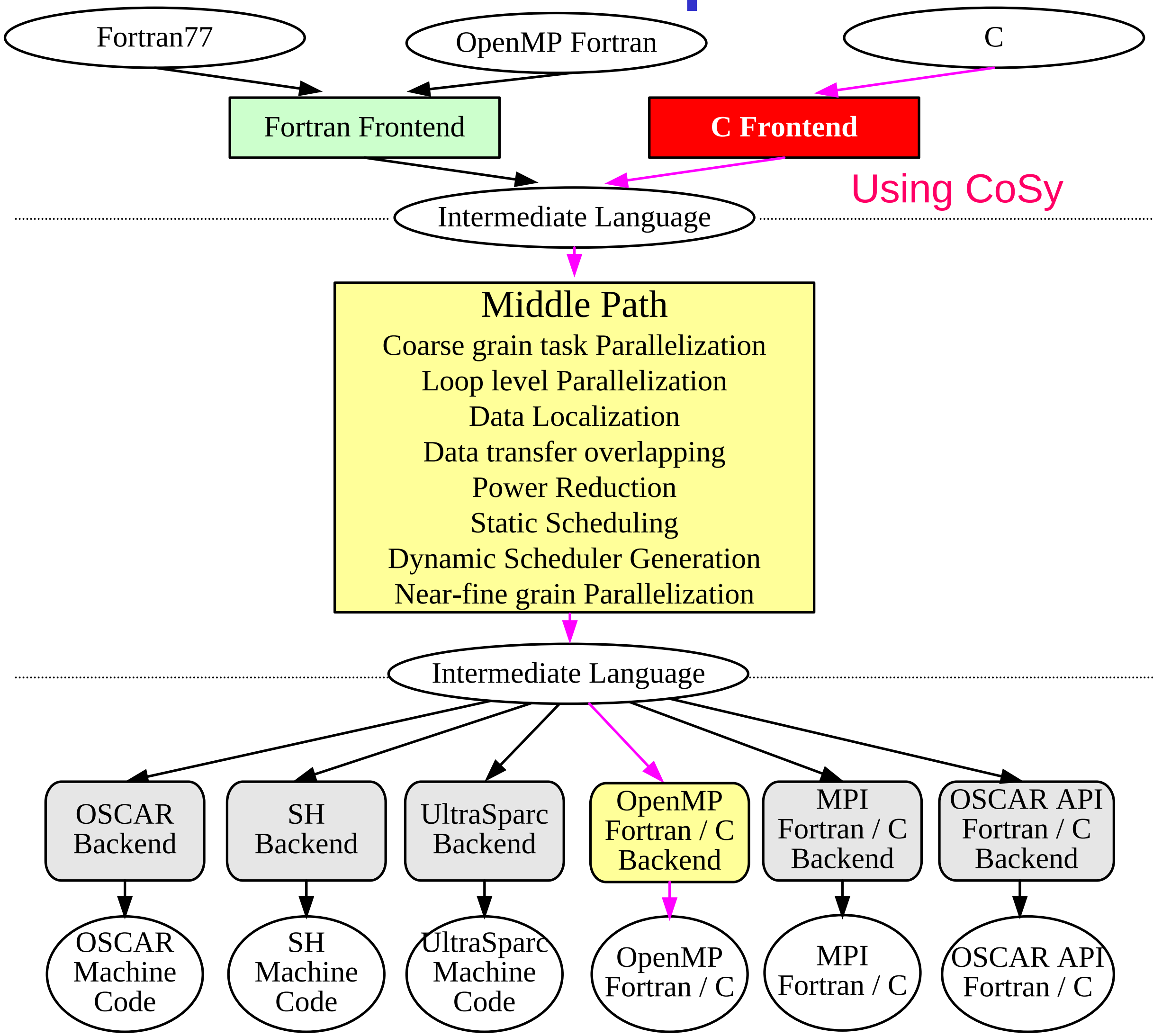


Energy Reduction in Real-time Processing



・**Deadline = Sequential Processing Time** x **1.0**

OSCAR Compiler’s Components



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C Frontend

Using CoSy

Intermediate Language

Middle Path

Coarse grain task Parallelization

Loop level Parallelization

Data Localization

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FrontEnd
parsing a program

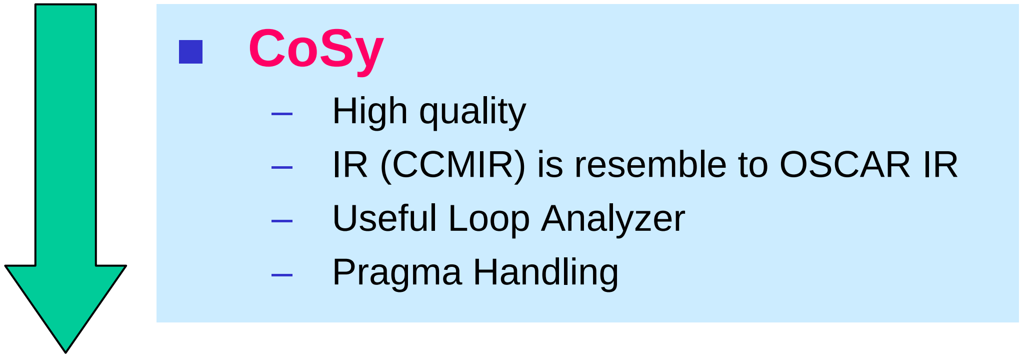
MiddlePath
optimization, parallelization

BackEnd
multi-target code generation

Evaluating on commercial machines

Why CoSy?

- **For rapid construction of a C compiler**
  - Avoidance of composing a C language parser from scratch



- **CoSy**
  - High quality
  - IR (CCMIR) is resemble to OSCAR IR
  - Useful Loop Analyzer
  - Pragma Handling

- **CoSy as an Intermediate Representation (IR) converter**
  - Development of an “engine” for generating OSCAR Intermediate Representation

OSCAR C Frontend using CoSy

CoSy Frontend
and some engines

```
int main()
{
  int i, sum=0;
  for (i=0; i<1000; i++)
    sum+=i;
  printf(“%d¥n”, sum);
  return 0;
}
```

Source C program

```
// PIR dump in summary format.
TYPES
...
EXPORT PROC main ...
DECLARE
    int4: i...
    int4: sum...
BEGIN
bb0:
...
    begin
    sum :=0
    goto bb1
bb1:
...
    if i^ < 1000 then bb3 ...
...
```

CoSy

- converting symbol tables
- CCMIR to OSCAR IR
- **analyzing loop information**
- parsing pragma lines
- …etc.

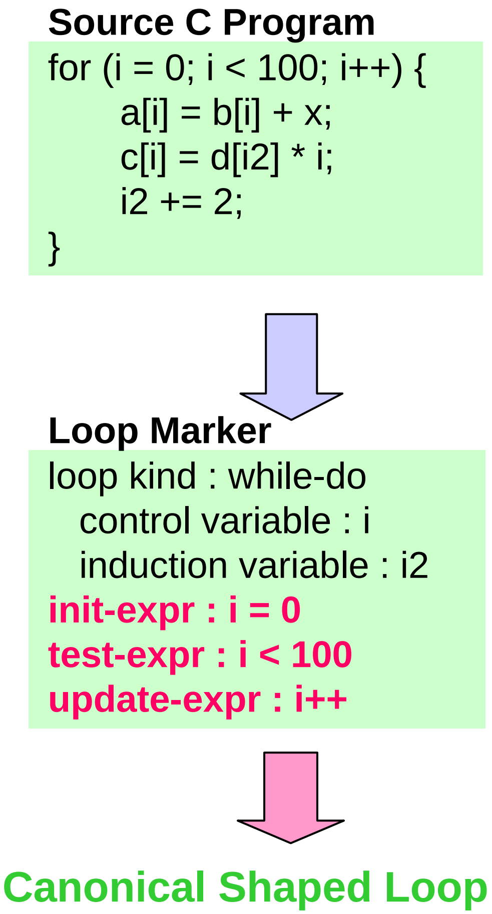
```
%*** System Table ***
file <sum.c>;
language <C>;

%% *** Constant Table ***
...
%% *** Type Table ***
...
% *** main ***
module main <*MAIN*>
 {
...
@block1(block)
...
  @bb1(block){
   $assign(V2,C1);
  }:4 % $assign
  @loop2(block){
   $do{
    !cfor(V1,C1,C2,C3);
   }
...
```

OSCAR

Loop Analyzer

- **Extraction of canonical shaped loop**
  - Equivalent to DO loops in FORTRAN
    - its iteration number will be determined when the execution of the loop starts
  - One of important factors for parallelization
- **Loop Marker of CCMIR**
  - Extraction of loop structures
  - Analyzing induction variables
- **Loop information**
  - Loop kind
    - while-do, repeat-until
  - Loop variable
    - loop control variables, loop induction variables
  - Important expressions
    - init-expr, test-expr, update-expr



Source C Program

```
for (i = 0; i < 100; i++) {
        a[i] = b[i] + x;
        c[i] = d[i2] * i;
        i2 += 2;
}
```

Loop Marker

```
loop kind : while-do
   control variable : i
   induction variable : i2
init-expr : i = 0
test-expr : i < 100
update-expr : i++
```

Canonical Shaped Loop

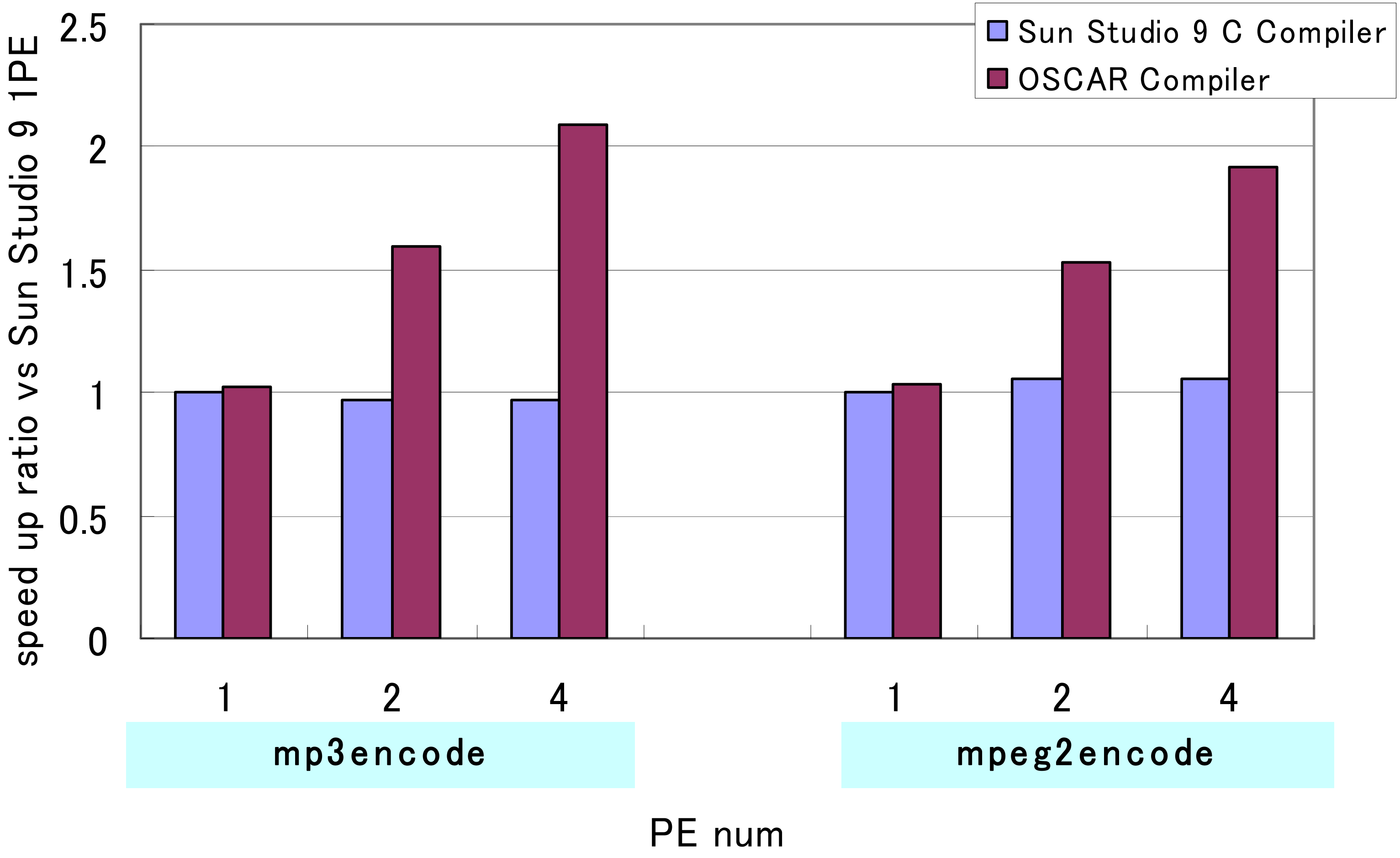
Preliminary Evaluation

- **Restriction of Source C Program**
  - Fortran-like C Program (Restricted C)
    - without recursive call
    - without pointer and structure
      - except for Arguments of Functions
  - with some directives
    - some hint information for analyzers not implemented yet

- Function's pointer arguments mustn't be aliased
- Supplying array shapes for pointers to arrays
- Some Information for Data Localization

- **Application**
  - mp3encode
    - Referencing "UZURA"
      - http://members.at.infoseek.co.jp/kitaurawa/cgi-bin/wiki.cgi
  - mpeg2encode
    - Derived from "MediaBench"
- **On a SMP Workstation**
  - Sun Ultra80 (4 Ultra SPARC II 450MHz)
    - Native parallelizing compiler : Sun Studio 9 C Compiler

Performance Evaluation Results on 4 processor workstation Sun Ultra80



- **About 2 times speed up against Sun Studio 9**

Conclusion

- **OSCAR Multigrain Parallelizing Compiler**
  - Multigrain Parallel Processing
  - Data Localization
  - Data transfer Overlapping
  - Power Reduction
- **C Language Support using CoSy**
  - Converting CCMIR to OSCAR IR
- **Preliminary Evaluation on a SMP workstation**
  - about 2 times speed up against Sun Studio 9
- **Future Works**
  - Performance Evaluations on Multi-core Processors
  - Performance tuning and Relaxing restrictions

Acknowledgements

- **A part of this research has been supported by**
  - NEDO “Advanced Heterogeneous Multiprocessor”
  - STARC “Automatic Parallelizing Compiler Cooperative Single Chip Multiprocessor”
  - NEDO “Multi core processors for real time consumer electronics”