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Hierarchical composition
Multiple concern management
Conclusions

Skeletons from grids to multicores

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Structured parallel programming

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Algorithmic skeletons

- Cole 1988 → common, parametric, reusable parallelism exploitation pattern
- languages & libraries since '90 (P3L, Skil, eSkel, ASSIST, Muesli, SkeTo, Mallba, Muskel, Skipper, BS, ...)
- high level parallel abstractions (parallel programming community)
  - hiding most of the technicalities related to parallelism exploitation
  - directly exposed to applicaion programmes

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Parallel design patterns

- Massingill, Mattson, Sanders 2000 → "Patterns for parallel programming" book (2006) (software engineering community)
- design patterns à la Gamma book
  - name, problem, solution, use cases, etc.
- concurrency, algorithms, implementation, mechanisms

Concept evolution

Parallelism

- parallelism exploitation patterns shared among applications
- separation of concerns:
  - system programmers → efficient implementation of parallel patterns
  - application programmers → application specific details

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New architectures

- *Heterogeneous* in Hw & Sw
- *Multicore* NUMA, cache coherent architectures

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New architectures

- *Heterogeneous* in Hw & Sw
- *Multicore* NUMA, cache coherent architectures

Further non functional concerns

- security, fault tolerance, power management, ...

Urgencies

→ Targeting multi/many cores

- different implementation issued and solutions
- completely different computational grains to be addressed

→ Targeting non functional concerns

- autonomic management of independent non functional concerns
- co-management of different non functional concerns

Urgencies

$\rightarrow$ Targeting multi/many cores

- different implementation issued and solutions
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$\rightarrow$ Targeting non functional concerns

- autonomic management of independent non functional concerns
- co-management of different non functional concerns

Structured parallel programming models

- can be exploited to address both issues
- synergies among the solutions may be exploited as well

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Targeting multicores

Targeting multi/many cores

Structured parallel programming on COW/NOW

Implementation template based

- P3L, eSkel, Muesli, SkeTo $\rightarrow$ collection of $\langle \mathit{Architecture}, \mathit{ProcessNetwork}, \mathit{Model} \rangle$

Macro Data Flow based

- Lithium/Muskel, Skipper, Calcium (Skandium) $\rightarrow$ compile skeletons to MacroDataFlow graphs + Dstributed MDF interpreter

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Emphasis

- communication latency hiding
- avoid unnecessary data copies

Multi/many core features

Shared memory hierarchy

- NUMA (C vs. M accesses, non uniform intercore interconnection strctures)
- chache coherence (snoopy vs. directory based)

Control abstractions

- threads (user vs. system space, completion vs. time sharing)
- processes

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Control abstractions

- threads (user vs. system space, completion vs. time sharing)
- processes

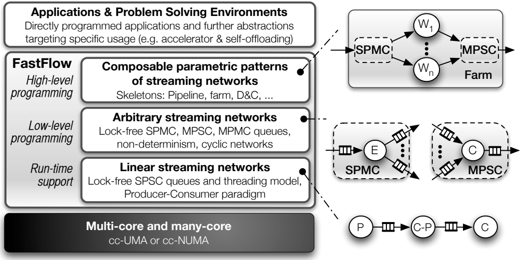
Focus

- synchronization overheads
- data access patterns
- thread-core binding, affinity scheduling

FastFlow

Advanced programming framework

- targeting multicores
- minimizing synchronization latencies
- streaming support through skeletons
- expandable
- open source



FastFlow: simple streaming networks

Single Producer Single Consumer (SPSC) queue

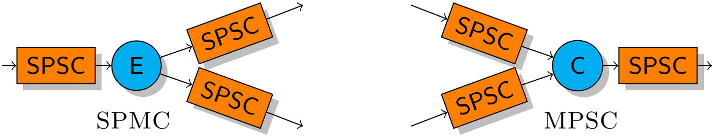
- uses results from the '80
- lock-free, wait-free
- no memory barriers for Total Store Order processor (e.g. Intel, AMD)
- single memory barrier for weaker memory consistency models (e.g. PowerPC)

→ very low latency in communications

FastFlow: simple streaming networks

Other queues: SPMC MPSC MPCP

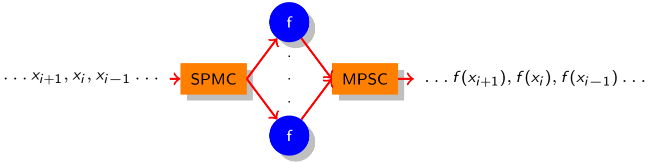
- one-to-many, many-to-one and many-to-many sychronization and data flow
- use a explicit arbiter thread
- providing lock-free and wait-free arbitrary data-flow graphs
- cyclic graphs (provably deadlock-free)



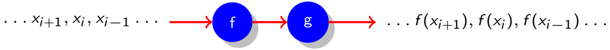
FastFlow: high level programming abstractions

Several "streaming" skeleton provided

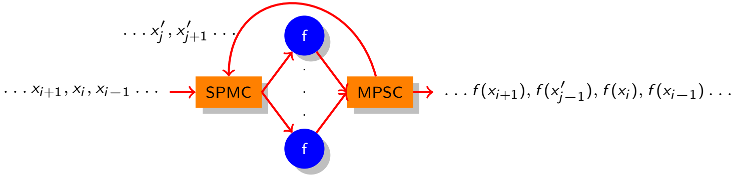
- farm



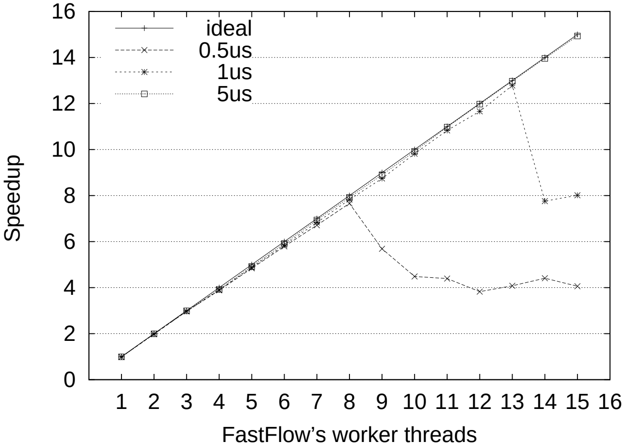
- pipeline



- farm with feedback



FastFlow: results



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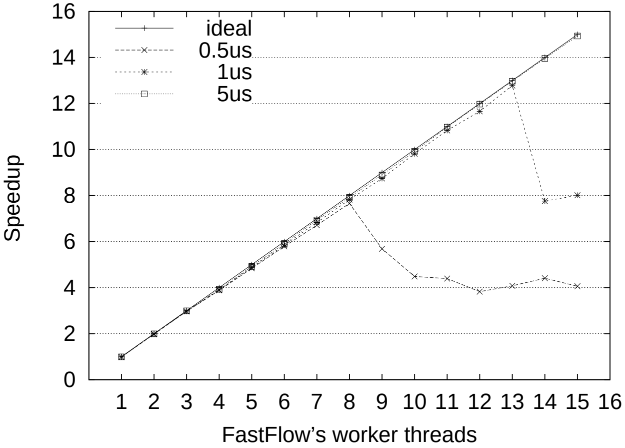

Speedup

Shows the advantage of lock free comms

FastFlow: results

Matrix multiplication

- parallel `for i` only

n. workers	matmul_ff_v1 Time	matmul_ff_v1 Speedup	matmul_ff_v2 Time	matmul_ff_v2 Speedup	matmul_OpenMP Time	matmul_OpenMP Speedup
4	2982.24	3.6	2691.74	4.0	2767.48	3.9
8	1495.87	7.2	1435.41	7.5	1455.73	7.4
12	1496.01	7.2	1431.34	7.5	1492.87	7.2
16	1495.74	7.2	1426.42	7.6	1433.31	7.5

FastFlow: results

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FastFlow vs. OpenMP

Comparable at quite coarse grain

FastFlow: different appls

Microbenchmarks

Benchmark	Parameters	Skeleton used	Speedup / #cores
Matrix Mult.	1024x1024	farm no collector	7.6 / 8
Quicksort	50M integers	D&C	6.8 / 8
Fibonacci	Fib(50)	D&C	9.21 / 8

FastFlow: different appls

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Real use cases

Application	Skeleton used	Measure	Value
YaDT-FF (C4.5 data mining)	D&C	Speedup	4.5-7.5
StochKit-FF (Gillespie)	farm	Scalabitily	10-11
SWPS3-FF (Gene matching)	farm no collector	GCUPS	12.5-34.5

FastFlow: offloading

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General purpose methodology

- use FastFlow as an efficient, fine grain *sw accelerator*

```
//<includes>
#define N 1024
int A[N][N],B[N][N],C[N][N];

int main() {

  // < init A,B,C>

  for(int i=0;i<N;++i) {
    for(int j=0;j<N;++j) {

      int _C=0;
      for(int k=0;k<N;++k)
        _C += A[i][k]*B[k][j ];
      C[i ][ j]=_C;

    }
  }

}
```

a) Original code (sequential)

```
//<includes; ff_includes>
#define N 1024
int A[N][N],B[N][N],C[N][N];

int main() {

  // < init A,B,C>

  ff :: ff_farm<> farm(true /* accel */);
  std :: vector<ff :: ff_node *> w;
  for(int i=0;i<NWORKERS;++i)
    w.push_back(new Worker);
  farm.add_workers(w);
  farm.run_then_freeze();

  for (int i=0;i<N;i++) {
    for(int j=0;j<N;++j) {

      task_t * task = new task_t(i,j);
      farm.offload(task);

    }
  }

  farm.offload((void *)ff :: FF_EOS);
  farm.wait(); // Here join

}
```

```
struct task_t {
  task_t(int i,int j):i(i),j(j) {}
  int i;
  int j;
};

class Worker: public ff :: ff_node {
public:
  void * svc(void * task) {
    task_t * t = (task_t *)task;

    int _C=0;
    for(int k=0;k<N;++k)
      _C += A[t->i][k]*B[k][t->j];
    C[t->i][t->j] = _C;

    delete t;
    return GO_ON;
  }
};
```

b) FastFlow accelerated code (parallel)

FastFlow pros and cons

Pros:

- very low overhead introduced
- high level abstractions available to application programmers
- streaming fully supported

Cons:

- parallelization of code requires “more code” w.r.t. classical approaches
- “structured” approach to parallelism required

Targeting non functional concerns

The scenario

Several important non functional features to be considered:

- performance → throughput, latency, load balancing
- security → data, code
- fault tolerance → checkpointing, recovery strategies
- power management → power/speed tradeoff

Non functional

- does not contribute to function computed
- policies & strategies most likely in the background of system programmers

Autonomic management

- separation of concerns: system programmers (NF) vs. appl programmers (FUN)

Behavioural skeletons

Def: Behavioural skeleton

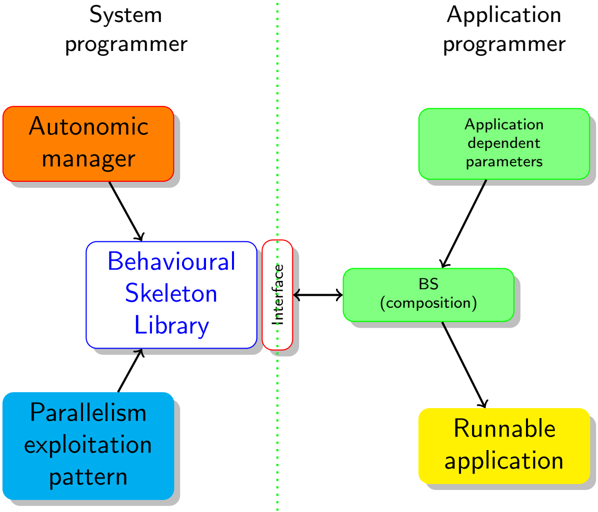
Co-design of a component including:

- parallelism exploitation pattern
- autonomic management of some non functional concern

Co design

- improves efficiency
- exploits knowledge relative to structure of the computation
- in the design and implementation of suitable management policies

BS: user view


System programmer
Application programmer
Autonomic manager
Application dependent parameters
Behavioural Skeleton Library
Interface
BS (composition)
Parallelism exploitation pattern
Runnable application

Sample Behavioural skeleton

Functional replication BS

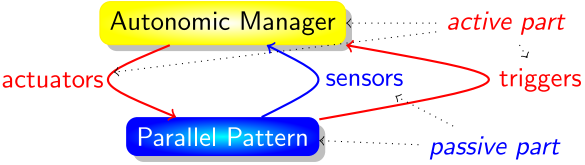
Parallel pattern

- Master-worker with variable number of workers.
- Master schedules tasks to available workers.

Performance manager

- Interarrival time faster than service time → increase parallelism degree, unless communication bandwidth is saturated.
- Interarrival time slower that service time → decrease the parallelism degree.
- Recent change → do not apply any action for a while.

Implementation: behavioural skeleton



Behavioural skeleton

- Triggers start manager activities
- Sensors determine pattern perception from the manager
- Actuators determine manager intervention possibilities

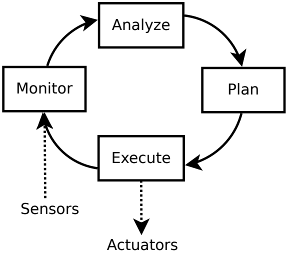
Implementation: manager

Monitor
- perceive pattern status

Analyse
- figure out policies

Plan
- devise strategy

Execute
- implement decisions on pattern



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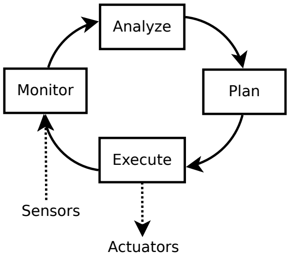

MAPE loop implementation

Cyclic execution of a JBoss business rule engine

- RULE :: Priority, Trigger, Condition $\rightarrow$ Action
- Rule set :: derived from user supplied *contract*

Hierarchical composition

Program $\rightarrow$ Composition of BS

- pipe(seq, farm(seq), seq)

Hierarchy of managers

- user contract directed to top level manager
- propagated (possibly modified) through manager tree

Management "exceptions"
manager not able to ensure contract

$\rightarrow$ raises violation to upper manager in hierarchy

$\rightarrow$ enters *passive* mode waiting for a new contract

Hierarchical composition

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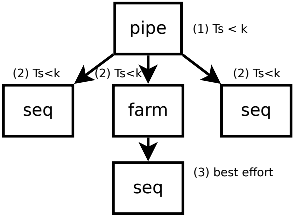

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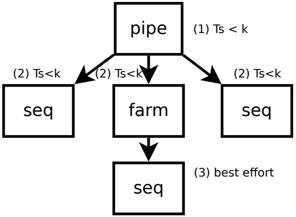

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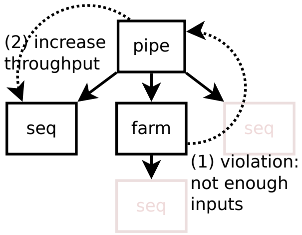

BS: sample run

Skeletons from grids to multicores

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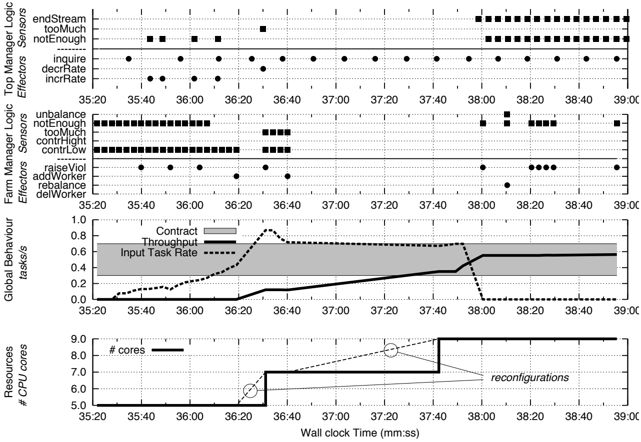
Medical image processing

- pipe(seq(getImage),
  farm(seq(renderImage)),
  seq(displayImage))
- contract $\rightarrow$ 0.3 to 0.7 images per second
- initial condition
  - enough processing resources
  - image provider stage too slow

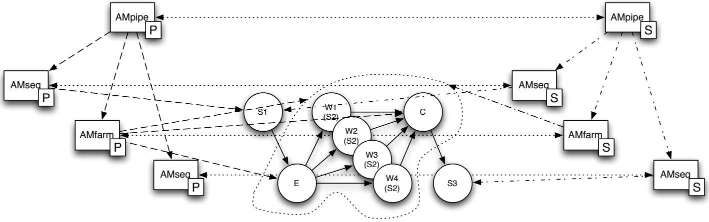
BS: sample run



Multiple concern management

Indipendent manager hierarchies

- take care of indipendent concerns (e.g. Performance and Security)
- must coordinate independently taken decisions
  - to avoid instability



BS: Coordination protocol

Fireable rule (Manager X) $R_z :: Trig_i, Cond_j, Prio_k \rightarrow a_1, \ldots, a_n$

Step 0 broadcast changes in the computation graph eventually induced by R_z

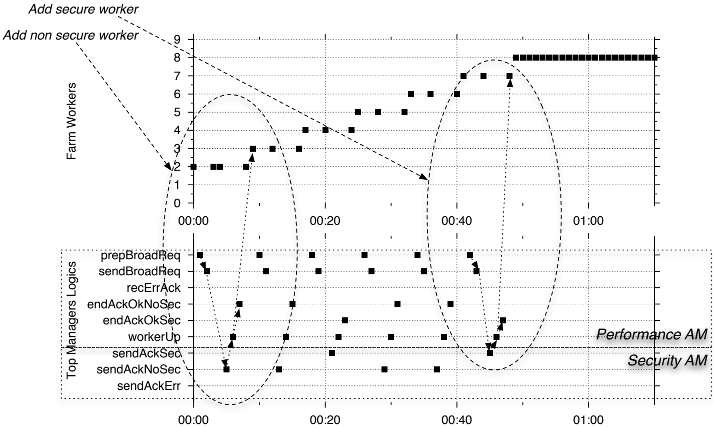
Step 1 gather answers from all other manager (hierarchies)

Step 2 analyze answers:

- all OK $\rightarrow$ perform $a_1, \ldots, a_n$
- at least one NOK $\rightarrow$ ABORT R_z & lower $Prio_k$
- require(Property$_m$) $\rightarrow$ perform $a'_1, \ldots, a'_{n'}$ such that Property$_m$ is ensured

BS: coordination protocol

program $\rightarrow$ farm(seq) contract :: parDegree=8



BS pros and cons

Pros:

- full decoupling of system and application programmer concerns
- reconfigurable autonomic management through JBoss rule engine
- two prototypes available: GCM BS (ProActive/GCM based) and LIBERO (pure Java/RMI, configurable action/sensor interface)

Cons:

- further investigation needed on multiple concern management
- compiler *contract* $\rightarrow$ *JBoss rules* needed

Conclusions

Skeletons from grids to multicores

Grids

- BS suitable to manage typical features of grids: heterogeneity, distribution, security, ...

Multicores

- efficient mechanisms supporting typical grains

Next step

- adopt BS like management to improve (at run time) the performance of FastFlow
- e.g. depending on current system behaviour
  - experiment, evaluate, adopt new skeleton composition e.g. farm(pipe(seq,seq)) $\rightarrow$ pipe(farm(seq), farm(seq))

References

- These slides available at
  `http://www.di.unipi.it/~marcod`
  follow "Papers" then "Talks" tabs
- FastFlow home page at
  `http://calvados.di.unipi.it/dokuwiki/doku.php?id=ffnamespace:about`
  source code (GPL) at
  `http://sourceforge.net/projects/mc-fastflow/`
- ProActive/GCM BS home page at
  `http://gridcomp.ercim.eu/content/view/26/34/`
- LIBERO prototype: ask author(s) at
  `marcod@di.unipi.it`

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Any questions?

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