Theft-Induced Checkpointing for Reconfigurable Dataflow Applications

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Presentation Outline

- **Motivation and background**
- Execution model
- Theft-induced checkpointing
- Experimental results
- Conclusions and Future Work

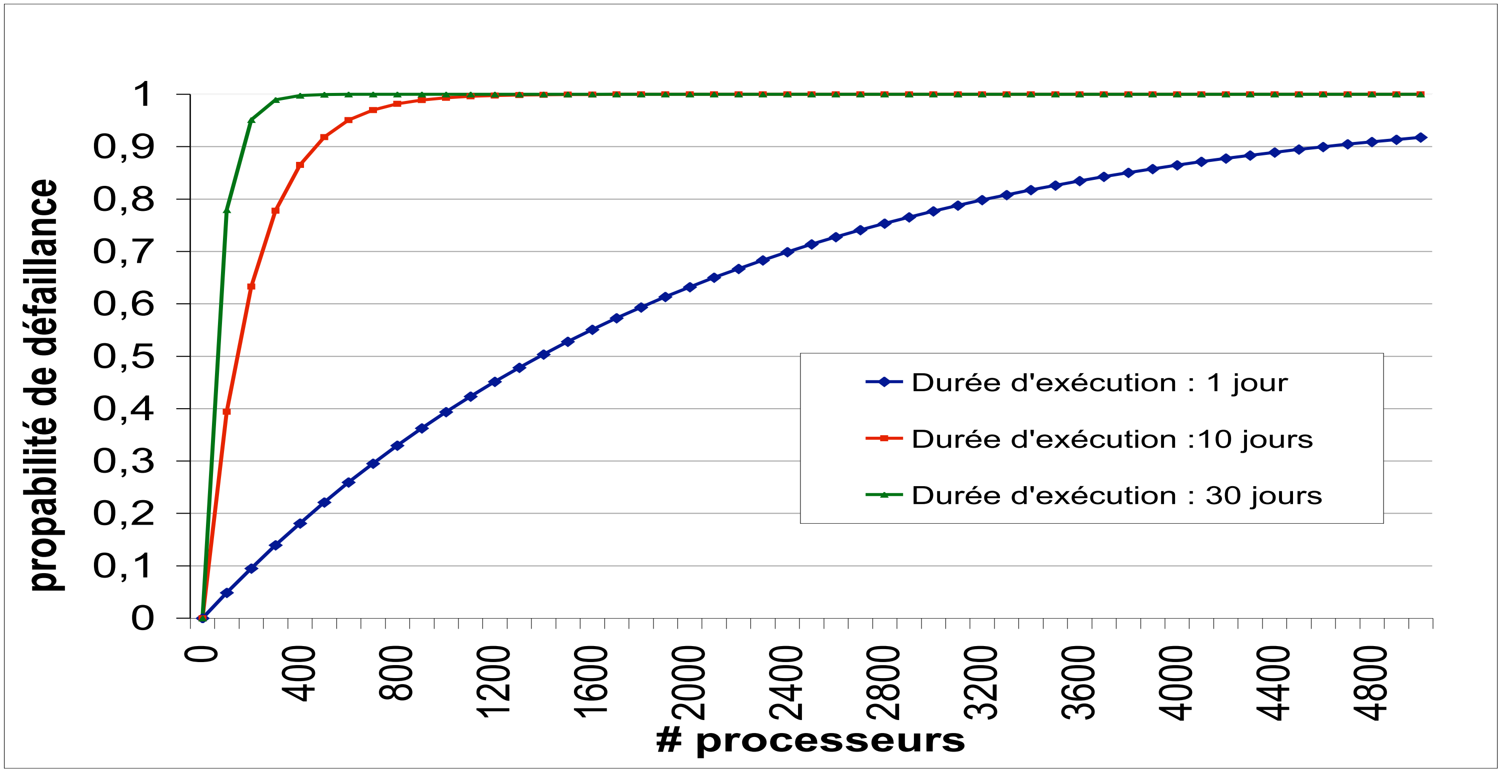
Target Application

- Large-Scale Global Computing Systems
  - (potentially) large number of nodes
  - volatility of nodes, e.g. dynamic run-time behavior
  - heterogeneous computing environment

- Dependability Problems
  - reliability issues of large number of nodes
  - without fault-tolerance mechanism application may be infeasible
    - MTBF may sink below application execution time

Unreliability in the absence of FT

- Computation on Cluster
  - MTBF = 2000 days (48,000h, approx. 5 1/2 years)
  - Unreliability of one node: $F(t) = 1 - R(t) = 1 - e^{-\lambda t}$



Fault-tolerance Approaches

- Redundancy
  - Duplication
  - Checkpointing
    - uncoordinated
    - coordinated
    - communication-induced
  - Message-logging
    - optimistic
    - pessimistic
    - causal

Comparing Protocols

- Coordination
  - processes coordinate to build consistent global state at time of checkpointing or recovery
- Heterogeneity
  - checkpoint state can be restored on variety of platforms
- Scope of recovery
  - local or global recovery
  - local recovery: only roll-back of crashed process is necessary

Roll-back Methods

- Log-based
  - relies on logging and replaying of messages
  - process can be modeled as sequence of interval states, each one representing a non-deterministic event [Strom & Yemini 1985]
- Checkpoint-based
  - periodically save global state of computation to stable storage [Chandy & Lamport 1985]
  - differ in the way processes are coordinated
  - and on the interpretation of a consistent global state

Checkpointing

- Coordinated checkpointing
  - coordination of all processes for building consistent state before writing checkpoint to safe storage
    - e.g. [Ftc-Charm++, CoCheck]
- Uncoordinated checkpointing
  - each process independently saves state
  - consistent global state is achieved in recovery phase
  - possibility of domino effect
- Communication induced checkpointing
  - compromise between coordinated and uncoordinated
  - consistent global state achieved by forcing additional checkpoints based on some information piggy bagged on application message [Baldone 1997]

Motivating Conclusion

- Lack of solutions for
  - large parallel applications
  - dynamic execution environment
  - heterogeneous processing environment
    - potentially SMP

- Portability
  - achieved by portable languages, e.g. Java
  - or compilation into application code, e.g. Porch
  - <u>but</u> not on the checkpointing method itself

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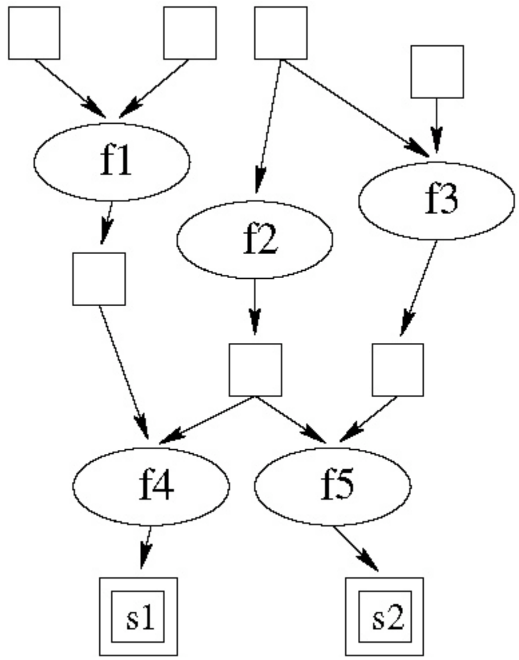
Definitions and Assumptions

- Application represented by Dataflow Graph
  - $G = (\mathcal{V}, \mathcal{E})$

    $\mathcal{V}$ finite set of vertices v_i

    $\mathcal{E}$ set of edges e_{jk} vertices $v_j, v_k \in \mathcal{V}$



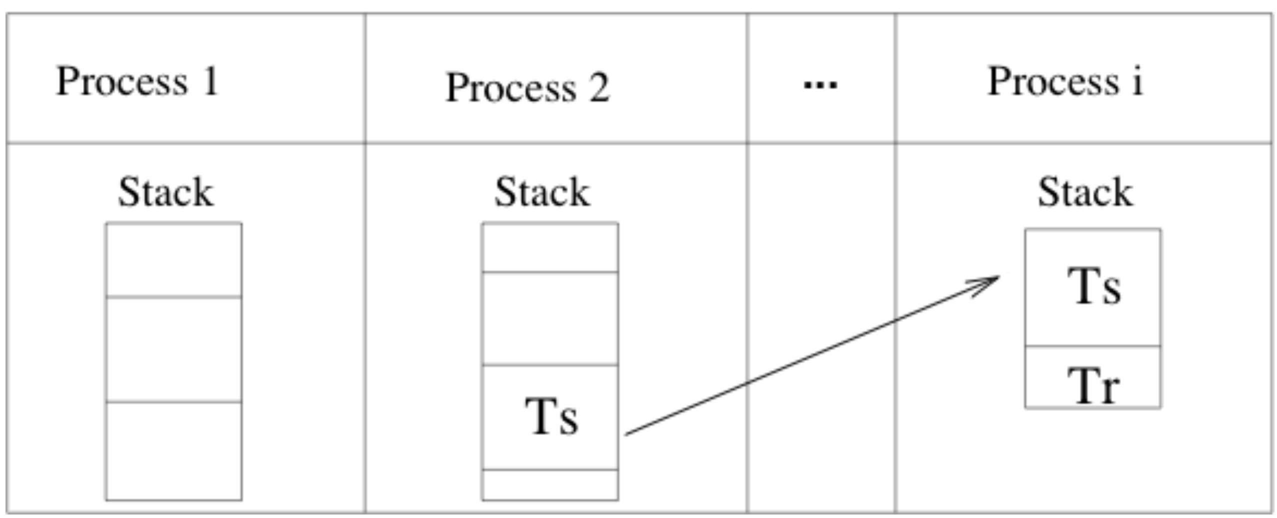
- Two kinds of tasks

  T_i Tasks
  in the traditional sense

  D_j Data tasks
  inputs and outputs

KAAPI Execution Model

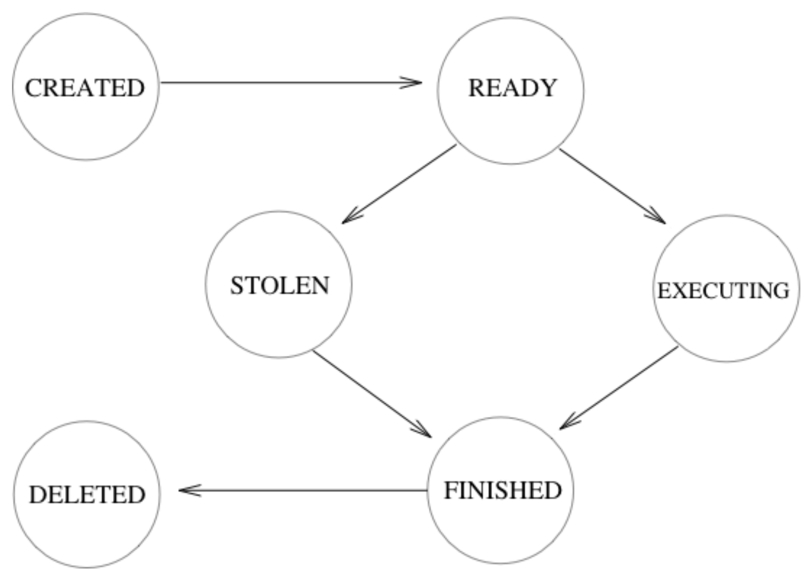
- **K**ernel for **A**daptive, **A**synchronous **P**arallel **I**nterface
  - implemented as C++ library
  - schedule programs at fine or medium granularity in distr. environment
  - KAAPI reference: http://moais.imag.fr/
- Relationship between processors and processes



Live-cycle of a Task in KAAPI

- Work-Stealing
  - primary method of scheduling workload
  - represents only communication between processes

- The states of a task
  - from a local process' point of view
  - in the context of work-stealing



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Theft-Induced Checkpointing

- State of the execution
  - based on macro dataflow graph
    - dynamic: changes during execution
    - portable: graph or portions of graph may be moved during execution
- Definition
  - *The macro dataflow graph G describes a platform-independent, and thus portable, consistent global state of the execution of an application.*

Theft-Induced Checkpointing

- Definition of a checkpoint
  - Checkpoints are with respect to a process P_i
  - The checkpoint of P_i consists of the entries of G_i, the process stack
    - i.e. its tasks and their associated inputs

    and **not of the task execution state** on the processor itself

- Important difference:
  - one simply checkpoints the tasks and their inputs

    => platform independent
  - one does NOT checkpoint the task's execution state

    => process context is platform dependent

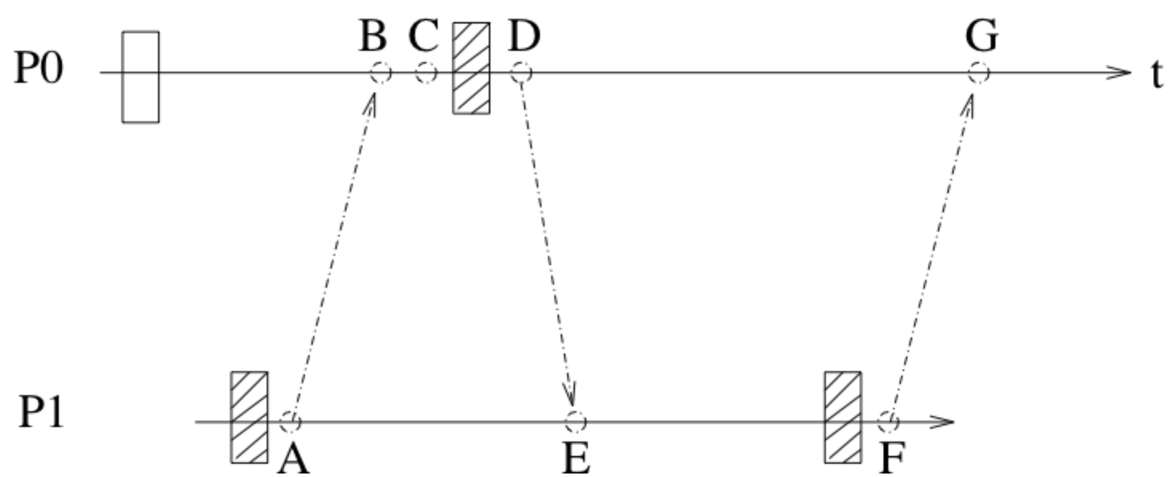
  - Note: the content of a checkpoint G_i is only the dataflow graph representing the "future of the computation".

Two Types of Checkpoints

- Local Checkpoint
  - each process takes a "local" checkpoint
    - at the expiration of a checkpointing interval τ
      - after completion of the currently executing task
- Forced Checkpoint
  - needed to address global consistency in the presence of communication
  - a checkpoint is takes as the result of work-stealing
  - actions on thief and victim are defined by protocol
- Both concepts will be used in the checkpointing protocol presented

Theft-Induced Checkpointing (TIC)

- *TIC* Protocol
  - victim P0 has ready-task(s)
  - thief P1 is created on idle resource and initiates a theft operation
  - each theft results in exactly 3 checkpoints
    - the checkpoints before events A and F contain only single task



TIC rollback

- Strenght of TIC: rollback of single crashed process
- Need to guarantee consistent global state of execution:
- Question 1:

  What does a process do that needs to send a message to a crashed process?

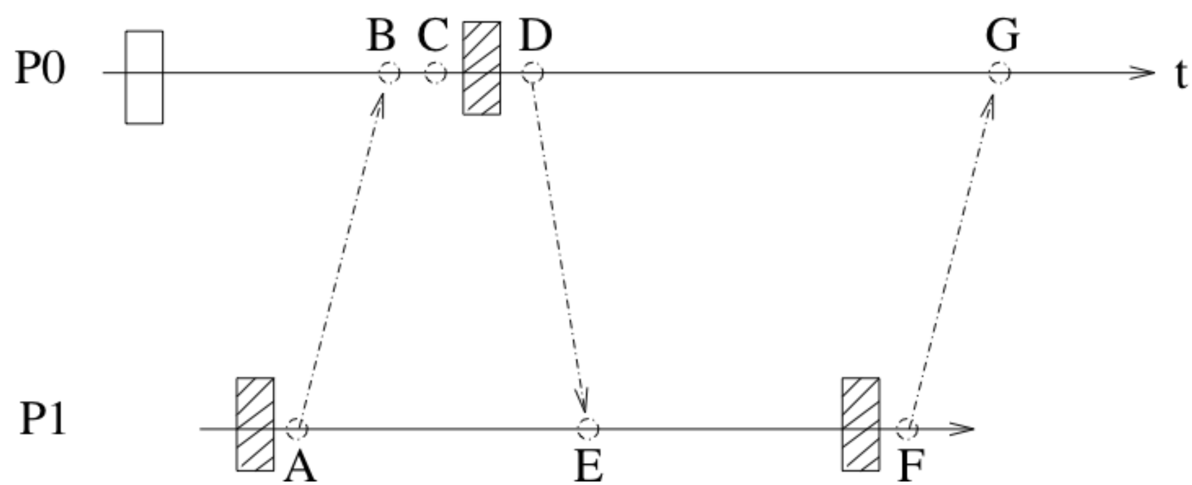
  - attempted communication with crashed process results in error
  - manager identifies the replacement processor

TIC rollback

- Question2:

  How can a process that is rolled back receive messages that it received after the last checkpoint and before the crash?

  - 1) loss of theft request (event A)
  - 2) crash of thief after event E but before able to checkpoint theft
  - 3) crash of victim after receiving result (event G) but before being able to checkpoint



Bound on TIC Rollback Loss

- What is the maximum computation time loss due to rollback?
  - T_1 : execution time of "parallel" application on single processor
    - note: not the same as execution time of sequential application execution
  - T_∞ : execution time on unlimited number of processors
  - p_i : processing time of task T_i

$$\text{Max loss} = \boldsymbol{\tau} + \max(p_i)$$

  - But how bad can this loss be?
    - in parallel application one can always assume $T_\infty \ll T_1$
    - and $p_i \leq T_\infty$

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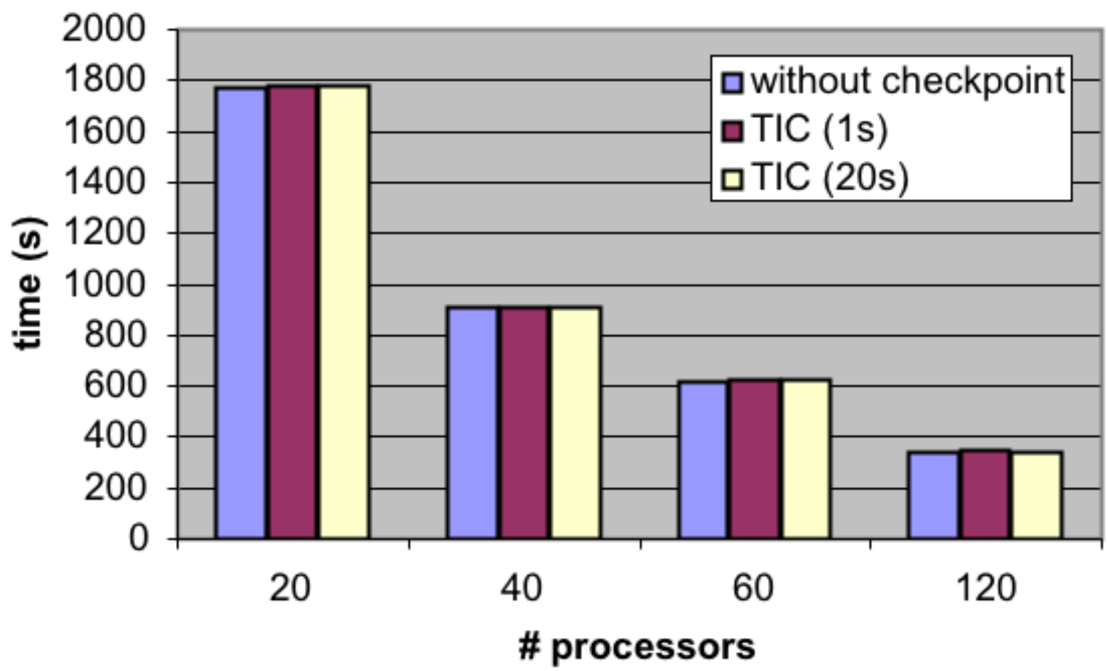
Experimental Results

- Application: DOCG
  - Combinatorial optimization, Branch & Bound algorithm
  - QAP: Quadratic Assignment Problem
  - Problem size: NUGENT 22

- Platform: iCluster2 at IMAG
  - 104 dual-processor Itanium2
  - 900 MHz
  - 100Base Ethernet

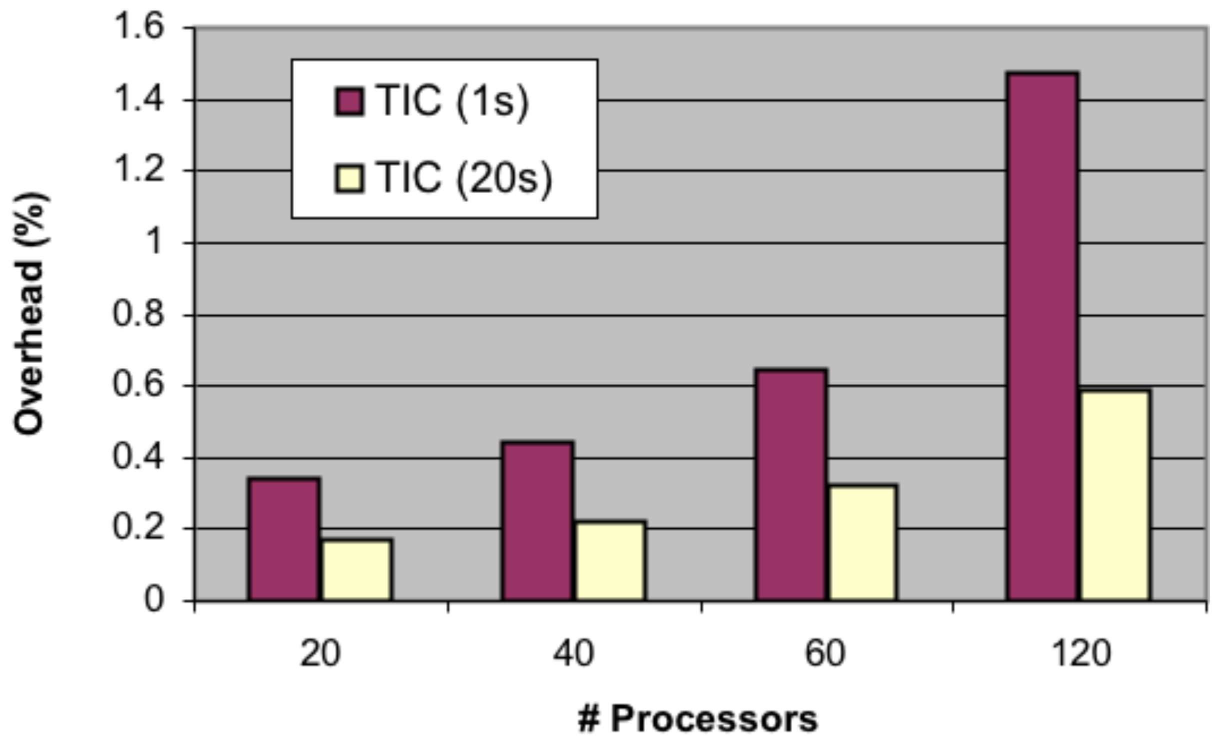
TIC Overhead

- Implemented using distributed checkpoint services
  - two checkpointing periods
  - max overhead observed: 1.5%



Relative TIC Overhead

- Differences observed
  - overhead increases as the number of processors increases
    - more forced checkpoints due to work-stealing



Conclusions

- Theft-Induced Checkpointing was introduced
- Requires only crashed processes to be rolled back
- State of application represented in portable fashion
  - macro dataflow graph
  - platform independent description of application state
- Roll-back possible in
  - dynamic environment
  - heterogeneous infrastructure
- Experimental results indicate low checkpointing overhead
- Max roll-back loss can be controlled
  - selection of suitable period, granularity of application

Questions?