Using computing resources with IBM ILOG CPLEX CO@W2015
Hardware resources
- Multiple cores/threads
- Multiple machines
- No machines

Software resources
- Interfacing with CPLEX
- Interacting with Python
Using more than one core/thread to solve a problem
Sequential branch and bound

Search tree

Pseudo code:

while !T.is_empty
    n = T.get_next()
    n.solve()
    if not (n.is_integer() || n.is_infeasible())
        j = n.fractional_index()
        v = n.fractional_value(j)
        T.create(n + "x[j] <= floor(v)")
        T.create(n + "x[j] >= ceil(v)")

min $c^T x$
$A x = b$
$x_j$ in $\{0, 1\}$
Sequential branch and bound

1. while !T.is_empty
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           n.is_infeasible())
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Sequential branch and bound

1. 

2. 

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while !T.is_empty
    T.lock()
    n = T.get_next()
    T.unlock()
    n.solve()
    if not (n.is_integer() ||
            n.is_infeasible())
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        T.create(n + "x[j] >= ceil(v)")
        T.unlock()
Parallel branch and bound

Thread 1

Thread 2
Parallel branch and bound

Thread 1

T.lock()

Thread 2

T.lock()
Parallel branch and bound

Thread 1

T.lock()
T.get_next()
T.unlock()

Thread 2

T.lock()
suspended
Parallel branch and bound

Thread 1

T.lock()
T.get_next()
T.unlock()

solve

Thread 2

T.lock()
suspended
T.get_next()
T.unlock()
Parallel branch and bound

Thread 1

1. T.lock()
2. T.get_next()
3. T.unlock()

4. solve

5. T.lock()
6. T.create()
7. T.unlock()

Thread 2

1. T.lock()

2. suspended

3. T.get_next()
4. T.unlock()

5. solve
6. T.lock()

7. suspended
Parallel branch and bound

Thread 1

T.lock()
T.get_next()
T.unlock()

solve

T.lock()
T.create()
T.unlock()

Thread 2

T.lock()
suspended

T.get_next()
T.unlock()

solve

T.lock()
suspended

T.create()
T.unlock()
Not deterministic!

Thread 1

T.lock()
T.get_next()
T.unlock()

solve

T.lock()
T.create()

T.unlock()

Thread 2

T.lock()

suspended

T.get_next()
T.unlock()
Not deterministic!

Thread 1

Thread 2

- Thread 2 solves blue instead of pink
- Light green and dark gray not even created
- Node selection dictates to continue under light blue and purple
Not deterministic!

Thread 1

- T.lock()
- T.get_next()
- T.unlock()

Thread 2

- T.lock()
- T.create()
- T.create()
- T.lock()
- T.get_next()
- T.unlock()

- solve

- ● Thread 2 solves light blue instead of pink
- ● and pink not even created
- ● Node selection dictates to continue under light blue and purple

Assume light blue must be processed to find optimal solution
Assume processing purple is enough to prove optimality

→ very different node counts, although same problem, code, hardware
Issues with non-determinism

- opportunistic behavior of OS scheduler
- very minor side effects (cache misses, page swaps, …) can change order of threads

This is a problem in practice:

<table>
<thead>
<tr>
<th>gmu-35-40</th>
<th>Time</th>
<th>Iterations</th>
<th>Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.31</td>
<td>2236199</td>
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<table>
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➔ results are not repeatable
➔ debugging becomes painful
➔ benchmarking is complicated
➔ assessment of algorithmic changes is difficult
“Is my new cut really helpful or is this just a random change?”

➔ **We need a solver that operates in a deterministic way!**
Deterministic multi-threading

**opportunistic**
OS scheduler, cache misses, swaps, ...
→ order in which lock is granted to threads is not deterministic

**deterministic**
make this order deterministic:
- use **deterministic time** → same in any run
- grant lock to first thread to arrive in **deterministic time**
Deterministic multi-threading

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**Kendo**

“Kendo: Efficient Deterministic Multithreading in Software”
→ use number of retired store instructions as time (x86)
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http://people.csail.mit.edu/mareko/asplos073-olszewski.pdf → use number of retired store instructions as time (x86)

**CPLEX**  deterministic time = number of array accesses
- works the same on all hardware
- explicit instrumentation of source code

```c
for (int i = 0; i < n; ++i)
    x[i] = y[i] * 0.5;
    DETCLOCK_INDEX_ARRAY (2 * i);
```
Deterministic multi-threading

- Deterministic threading is not for free
  - settle for a particular path through the search tree
  - increases wait/idle times in locks

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Performance is based on measurements and projections using standard IBM benchmarks in a controlled environment. The actual throughput or performance that any user will experience will vary depending upon many factors, including considerations such as the amount of multiprogramming in the user’s job stream, the I/O configuration, the storage configuration, and the workload processed. Therefore, no assurance can be given that an individual user will achieve results similar to those stated here.
Deterministic multi-threading

➢ Deterministic threading is not for free
  • settle for a particular path through the search tree
  • increases wait/idle times in locks

➢ Deterministic threading is unrelated to performance variability
  • parallel cut loop is still meaningful

➢ CPLEX extensions of Kendo framework allow efficient parallel cutloop
  ➔ opportunistic code, but results are deterministic

➢ All parallel algorithms in CPLEX are available as opportunistic/deterministic
  ➔ select at runtime with a parameter
Using more than one machine to solve a problem
Distributed parallel MIP

CPLEX implements distributed parallel MIP solving

- one master process to coordinate the search
- several worker processes to perform the heavy lifting
- usually one master/worker per machine (can configure otherwise)
- communication only between master and workers
Distributed parallel MIP

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- 3 different ways of communication:

  ssh → master starts workers via ssh
        → communication via pipes

  TCP/IP → workers run a server-like process to which master connects
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  MPI → all processes run within an MPI communicator
        → communication via MPI functions
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- 2 phases:
  1. “rampup” → create an initial set of open nodes
  2. “tree search” → perform distributed parallel b&b
Phase I: rampup

1. master runs presolve to create a root node
Phase I: rampup

1. master runs presolve to create a root node

2. master sends root to workers
Phase I: rampup

1. master runs presolve to create a root node

2. master sends root to workers

3. each worker starts b&b with different parameters
   → each worker produces a different tree
Phase I: rampup

1. master runs presolve to create a root node

2. master sends root to workers

3. each worker starts b&b with different parameters
   → each worker produces a different tree

4. master eventually
   - stops workers
   - selects a winner
   - collects open nodes from winner
   → list of “supernodes”
Phase II: tree search

5. master starts with list of supernodes
Phase II: tree search

5. master starts with list of supernodes

6. master sends a supernode to each worker
Phase II: tree search

5. master starts with list of supernodes

6. master sends a supernode to each worker

7. workers solve supernode as MIP
Phase II: tree search

5. master starts with list of supernodes
6. master sends a supernode to each worker
7. workers solve supernode as MIP

8. Master can
   - send new supernodes (if idle)
   - grab nodes to produce new supernodes
   - pause supernode (exchange)
Distributed parallel MIP

Variants/improvements

1. exchange information (incumbents, bound tightenings, ...)

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Distributed parallel MIP

Variants/improvements

1. exchange information (incumbents, bound tightenings, ...)

2. in rampup, start some workers with special settings
   - aggressive heuristics → quickly find good solutions
   - aggressive cuts → quickly improve dual bound
   - ...

Distributed parallel MIP

Variants/improvements

1. exchange information (incumbents, bound tightenings, ...)

2. in rampup, start some workers with special settings
   - aggressive heuristics → quickly find good solutions
   - aggressive cuts → quickly improve dual bound
   - ...

3. never stop the rampup phase → exploit performance variability

Performance is based on measurements and projections using standard IBM benchmarks in a controlled environment. The actual throughput or performance that any user will experience will vary depending upon many factors, including considerations such as the amount of multiprogramming in the user's job stream, the I/O configuration, the storage configuration, and the workload processed. Therefore, no assurance can be given that an individual user will achieve results similar to those stated here.
Solving a problem without a machine
What if no local resources to solve model?

- model too hard
- only need to solve once in a while
- ...

→ solve in the cloud
What if no local resources to solve model?

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→ solve in the cloud

1. submit model to cloud
CPLEX in the cloud

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→ solve in the cloud

1. submit model to cloud
2. model solved on cloud
3. get solution from cloud
Two ways to access CPLEX in the cloud

1. Dropsolve

   www.ibm.com/software/analytics/docloud
   dropsolve-oaas.docloud.ibmcloud.com/software/analytics/docloud

   Drag and drop your model file from disk to web browser
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Two ways to access CPLEX in the cloud

2. REST API

   https://developer.ibm.com/docloud/
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Access the solve service via its REST API
CPLEX in the cloud

Two ways to access CPLEX in the cloud

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Access the solve service via its REST API

• ready-to-use clients provided for Java™ and Python, e.g.

```java
JobExecutor executor = JobExecutorFactory.createDefault();
JobClient jobclient = JobClientFactory.createDefault(BASE_URL,
          APIKEY_CLIENTID);
jobclient.newRequest().input(new File("model.mps"))
    .output(new File("x.sol"))
    .execute(executor).get();
```

• With any HTTP client (cURL, ...)

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CPLEX in the cloud

Sign up for a free trial

www.ibm.com/software/analytics/docloud
https://developer.ibm.com/docloud/

free CPLEX community edition
www.cplex.com
Exploiting existing software resources
Interfacing with CPLEX

\[ \min c^T x \]
\[ Ax = b \]
Interfacing with CPLEX

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Interfacing with CPLEX

**Optimization Programming Language (OPL)**

- write models in a more descriptive form
- write models in a more compact form
- faster prototyping, easier maintenance
- easier access to data (Excel, database, ...)

\[ \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} x_{ijk} \leq 1 \text{ for } i \text{ in } I \]

```opl
forall (i in I)
  sum (j in J)
    sum (k in K)
      x[i][j][k] <= 1;
```

- scriptable
- model editor
- IDE support (eclipse based)
Interfacing with CPLEX
Interfacing with CPLEX

```plaintext
range Periods = 1..20; // Periods that make up the game.
int nplayers = 7; // Number of players on field
range Positions = 0..3; // The different positions
int G = 0; int D = 1;
int M = 2; int S = 3;
int Formation[Positions] = [1, 2, 3, 1]; // The formation for which we optimize

tuple Player {
    string name; // Players we need to schedule
    {int} play;
};
[Player] Players = {
    "Chris", {M, D}, "Andy", {M}, "Richie", {M, D},
    "Justin", {M}, "Steve", {D}, "Cory", {G}};

float avg = card(Periods) * nplayers / card(Players);

// Decision variables
dvar float+ eplus[Players];
dvar float+ eminus[Players];
dvar boolean x[Periods][player in Players][p in Positions] in 0..((p in player.play) ? 1 : 0);
minimize sum(p in Players) {eplus[p] + eminus[p]};
subject to {
    // Each player can play at most one position
    forall (player in Players)
        forall (period in Periods)
            sum(p in Positions) x[period][player][p] <= 1;
    // Correct number of players for each position
    forall (p in Positions) forall (period in Periods)
        sum (player in Players : p in player.play)
            x[period][player][p] == Formation[p];

    // Calculates minutes above/below average
    forall (player in Players)
        sum (p in player.play) sum (period in Periods) x[period][player][p] - avg == eplus[player] - eminus[player];
}
```
docplex

Most recent addition

- [https://pypi.python.org/pypi/docplex](https://pypi.python.org/pypi/docplex)
- pure Python modeling API (no native code)
- open source (pypi, github)
- prepared to connect to local or cloud CPLEX

→ write your model in Python
→ hook up with the whole Python software ecosystem
docplex

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For example

- Equitable Coach Problem
- list of players from the internet (web service)
- graphical display of solution

→ use iPython/Jupyter notebook and Python libraries
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