Systems, Networks & Concurrency 2020

5

Data Parallelism

Uwe R. Zimmer - The Australian National University

Data Parallelism

References

[Bacon98]
J. Bacon
Concurrent Systems
1998 (2nd Edition) Addison Wesley Longman Ltd, ISBN 0-201-17767-6

[Ada 2012 Language Reference Manual]
see course pages or http://www.ada-auth.org/standards/ada12.html

[Chapel 1.13 Language Specification Version 0.981]
see course pages or
http://chapel.cray.com/docs/latest/_downloads/chapelLanguageSpec.pdf
released on 7. April 2016

Data Parallelism

Vector Machines

Vectorization

```
type Real_Precision = Float
type Scalar = Real_Precision
type Vector = [Real_Precision]
scale :: Scalar -> Vector -> Vector
scale scalar vector = map (scalar *) vector
```


Data Parallelism

Vector Machines

Vectorization

Potentially concurrent, yet:

Executed sequentially.

```
type Real_Precision = Float
type Scalar = Real_Precision
type Vector = [Real_Precision]
scale :: Scalar -> Vector -> Vector
scale scalar vector = map (scalar *) vector
```


Data Parallelism

Vector Machines

Vectorization

Executed in parallel.

```
import Control.Parallel.Strategies
type Real_Precision = Float
type Scalar = Real_Precision
type Vector = [Real_Precision]
scale :: Scalar -> Vector -> Vector
scale scalar vector = parMap rpar (scalar *) vector
```

This **may be faster or slower** than a sequential execution.

Data Parallelism

Vector Machines

Vectorization

```
type Real    is digits 15;
type Vectors is array (Positive range <>) of Real;
function Scale (Scalar : Real; Vector : Vectors) return Vectors is
     Scaled_Vector : Vectors (Vector'Range);
  begin
     for i in Vector'Range loop
        Scaled_Vector (i) := Scalar * Vector (i);
     end loop;
     return Scaled_Vector;
  end Scale;
```


Data Parallelism

Vector Machines

Vectorization

Buzzword collection: AltiVec, SPE, MMX, SSE, NEON, SPU, AVX, …

Translates into **CPU-level vector operations**

```
type Real    is digits 15;
type Vectors is array (Positive range <>) of Real;
function Scale (Scalar : Real; Vector : Vectors) return Vectors is
     Scaled_Vector : Vectors (Vector'Range);
  begin
     for i in Vector'Range loop
        Scaled_Vector (i) := Scalar * Vector (i);
     end loop;
     return Scaled_Vector;
  end Scale;
```

Combined with **in-lining**, **loop unrolling** and **caching** this is as fast as a single CPU will get.

Data Parallelism

Vector Machines

Vectorization

Function is **"promoted"**

```
const Index = {1 .. 100000000},
      Vector  : [Index] real = 1.0,
      Scale   : real = 5.1,
      Scaled  : [Vector] real = Scale * Vector;
```


Data Parallelism

Vector Machines

Vectorization

Function is **"promoted"**

```
const Index = {1 .. 100000000},
      Vector  : [Index] real = 1.0,
      Scale   : real = 5.1,
      Scaled  : [Vector] real = Scale * Vector;
```

Translates into **CPU-level vector operations** *as well as* **multi-core** or **fully distributed operations**

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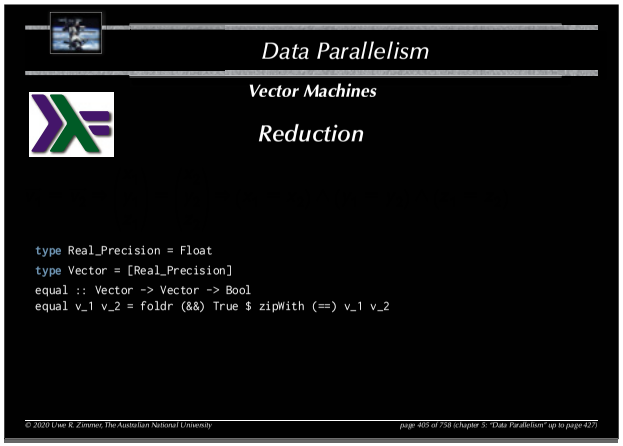

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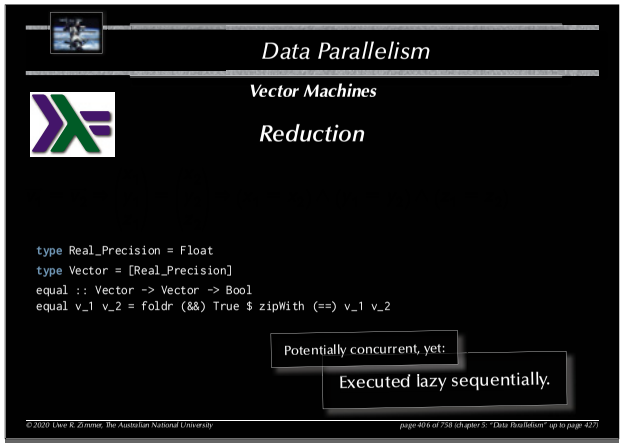

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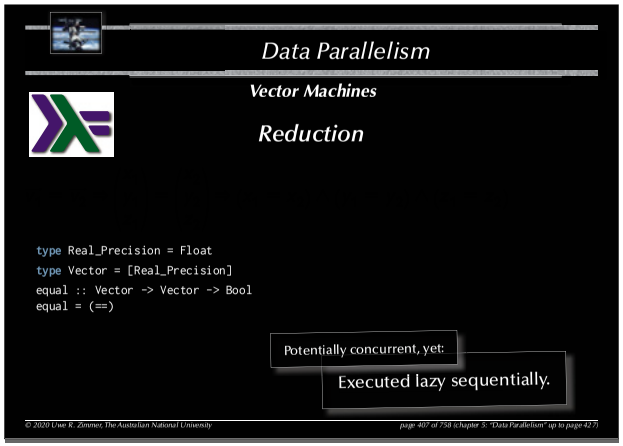

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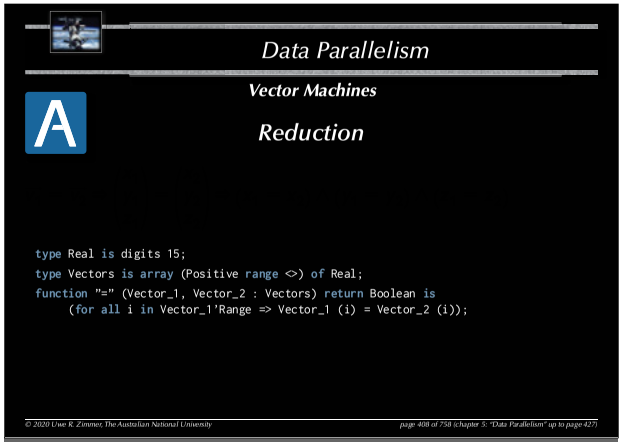

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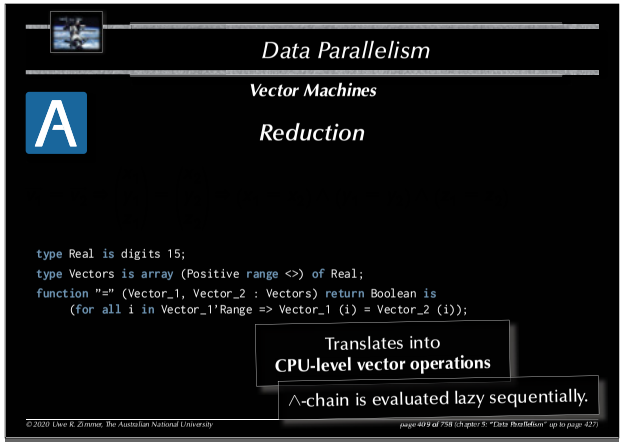

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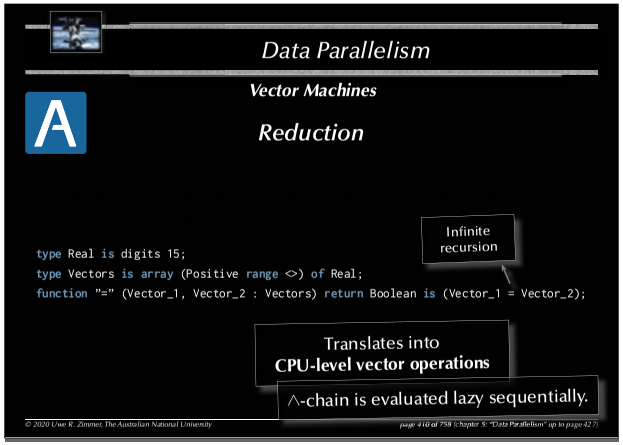

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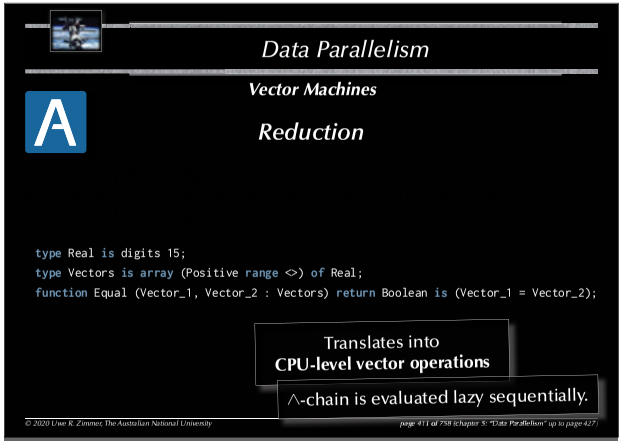

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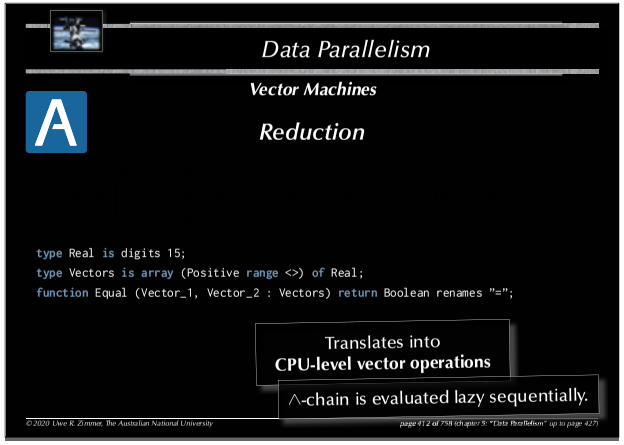

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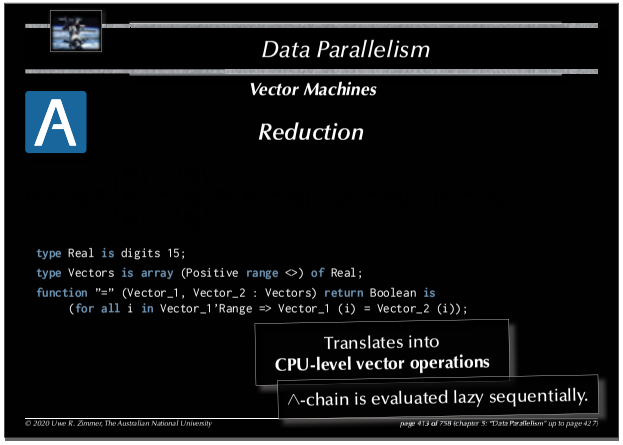

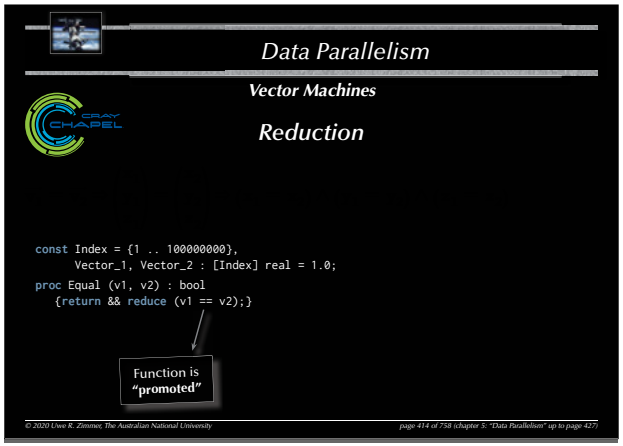
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Vector Machines
Reduction
const Index = {1 .. 100000000},
Vector_1, Vector_2 : [Index] real = 1.0;
proc Equal (v1, v2) : bool
{return && reduce (v1 == v2);}
Function is "promoted"
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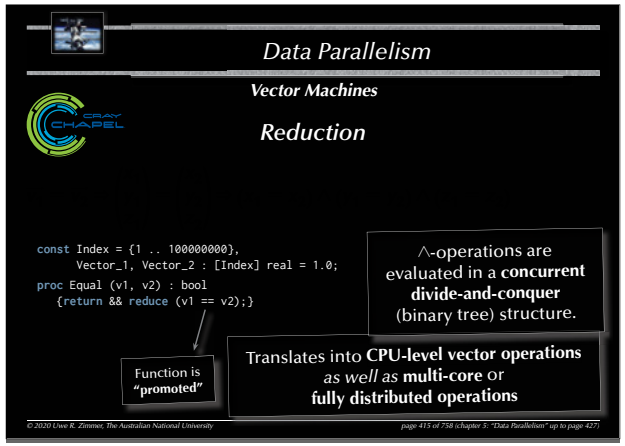
Data Parallelism
Vector Machines
Reduction
const Index = {1 .. 100000000},
Vector_1, Vector_2 : [Index] real = 1.0;
proc Equal (v1, v2) : bool
{return && reduce (v1 == v2);}
∧-operations are evaluated in a concurrent divide-and-conquer (binary tree) structure.
Function is "promoted"
Translates into CPU-level vector operations as well as multi-core or fully distributed operations
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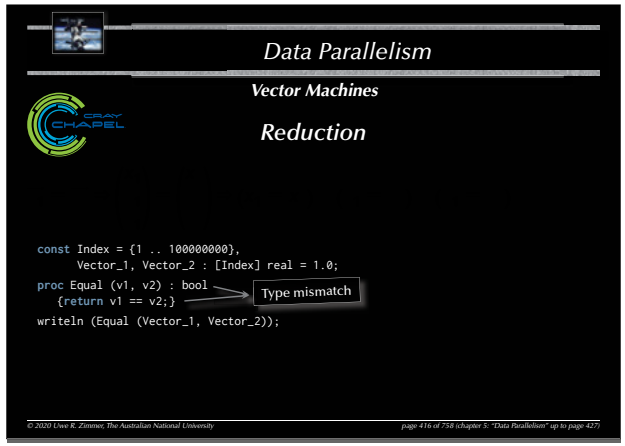
Data Parallelism
Vector Machines
Reduction
const Index = {1 .. 100000000},
Vector_1, Vector_2 : [Index] real = 1.0;
proc Equal (v1, v2) : bool
{return v1 == v2;}
Type mismatch
writeln (Equal (Vector_1, Vector_2));
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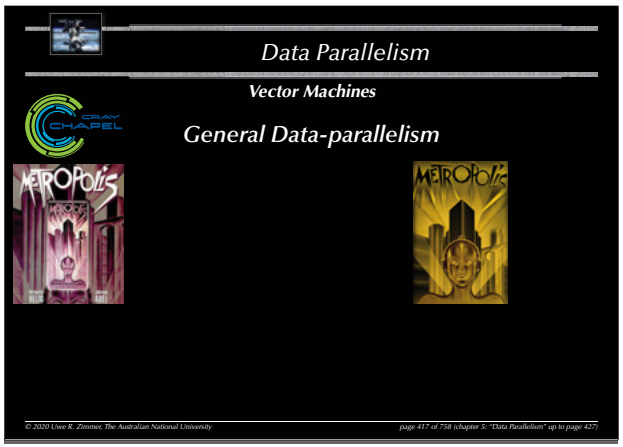
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Vector Machines
General Data-parallelism
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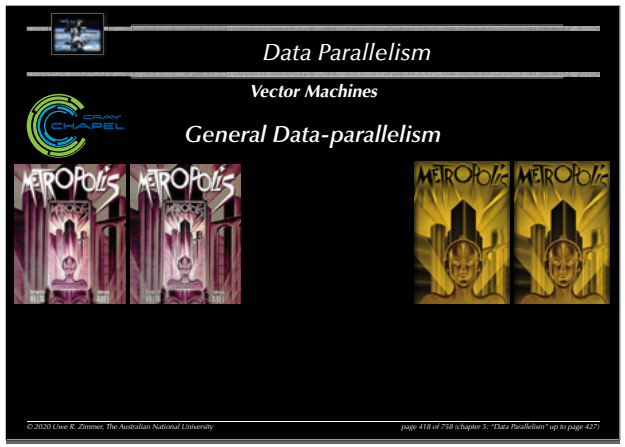
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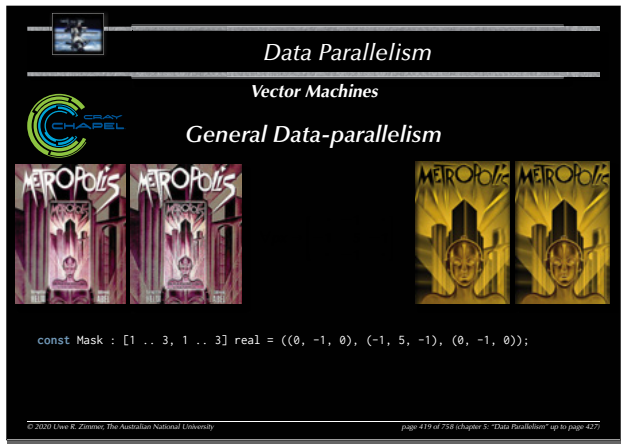
Data Parallelism
Vector Machines
General Data-parallelism
const Mask : [1 .. 3, 1 .. 3] real = ((0, -1, 0), (-1, 5, -1), (0, -1, 0));
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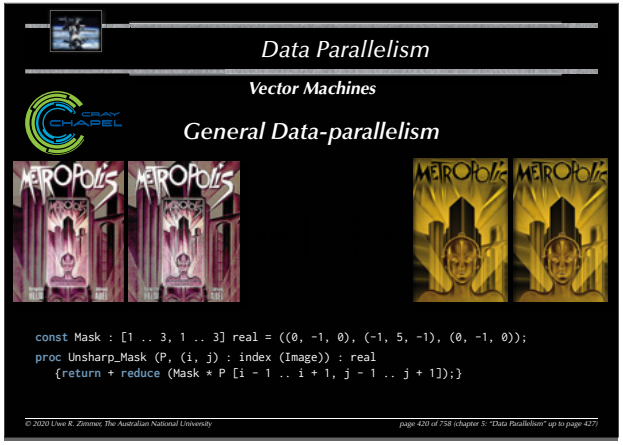
Data Parallelism
Vector Machines
General Data-parallelism
const Mask : [1 .. 3, 1 .. 3] real = ((0, -1, 0), (-1, 5, -1), (0, -1, 0));
proc Unsharp_Mask (P, (i, j) : index (Image)) : real
{return + reduce (Mask * P [i - 1 .. i + 1, j - 1 .. j + 1]);}
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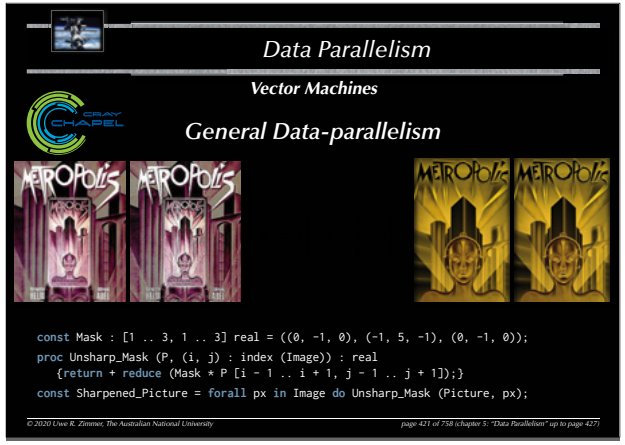
Data Parallelism
Vector Machines
General Data-parallelism
const Mask : [1 .. 3, 1 .. 3] real = ((0, -1, 0), (-1, 5, -1), (0, -1, 0));
proc Unsharp_Mask (P, (i, j) : index (Image)) : real
{return + reduce (Mask * P [i - 1 .. i + 1, j - 1 .. j + 1]);}
const Sharpened_Picture = forall px in Image do Unsharp_Mask (Picture, px);
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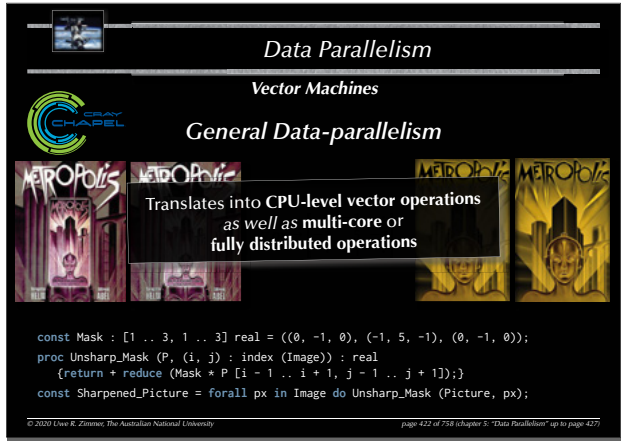
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Translates into CPU-level vector operations as well as multi-core or fully distributed operations
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const Sharpened_Picture = forall px in Image do Unsharp_Mask (Picture, px);
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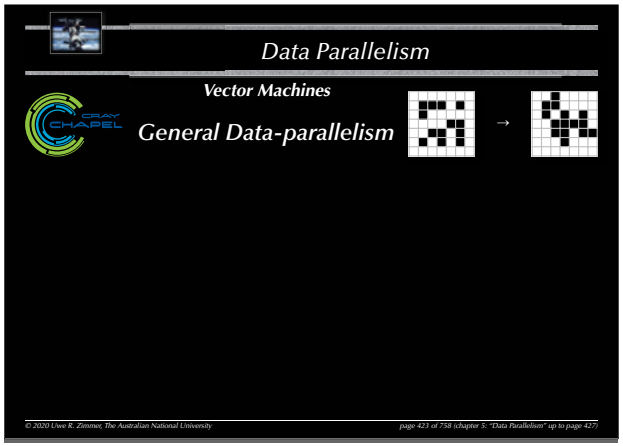
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→
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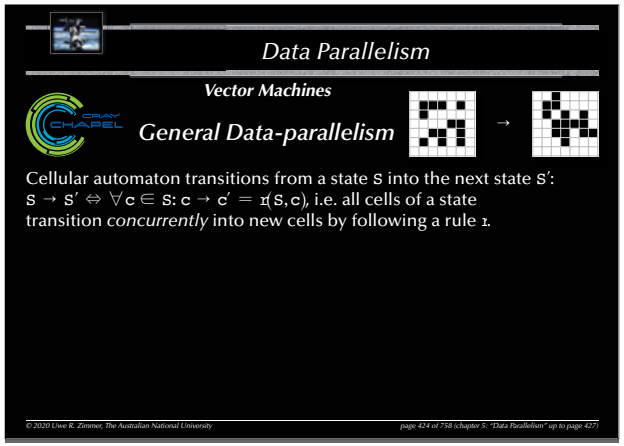
Data Parallelism
Vector Machines
General Data-parallelism
→
Cellular automaton transitions from a state s into the next state s′:
s → s′ ⇔ ∀c ∈ s: c → c′ = r(s, c), i.e. all cells of a state
transition concurrently into new cells by following a rule r.
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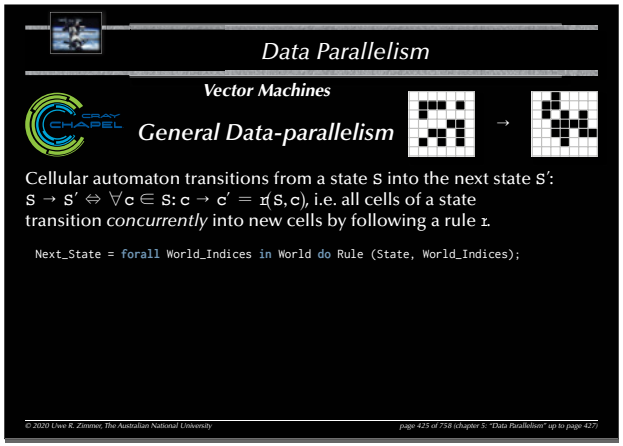
Data Parallelism
Vector Machines
General Data-parallelism
→
Cellular automaton transitions from a state s into the next state s′:
s → s′ ⇔ ∀c ∈ s: c → c′ = r(s, c), i.e. all cells of a state
transition concurrently into new cells by following a rule r.
Next_State = forall World_Indices in World do Rule (State, World_Indices);
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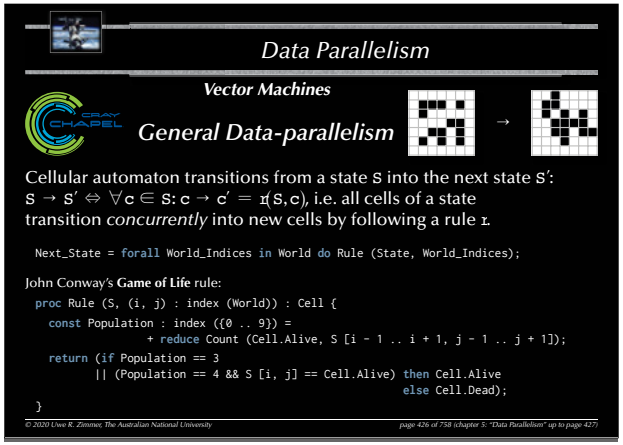
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→
Cellular automaton transitions from a state s into the next state s′:
s → s′ ⇔ ∀c ∈ s: c → c′ = r(s, c), i.e. all cells of a state
transition concurrently into new cells by following a rule r.
Next_State = forall World_Indices in World do Rule (State, World_Indices);
John Conway's Game of Life rule:
proc Rule (S, (i, j) : index (World)) : Cell {
const Population : index ({0 .. 9}) =
+ reduce Count (Cell.Alive, S [i - 1 .. i + 1, j - 1 .. j + 1]);
return (if Population == 3
|| (Population == 4 && S [i, j] == Cell.Alive) then Cell.Alive
else Cell.Dead);
}
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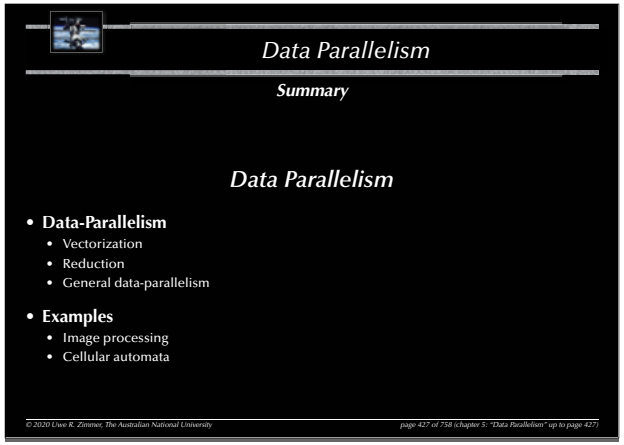
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Reduction
General data-parallelism
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Cellular automata
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