Parallel Techniques

- Embarrassingly Parallel Computations
- Partitioning and Divide-and-Conquer Strategies
- Pipelined Computations
- Synchronous Computations
- Asynchronous Computations
- Load Balancing and Termination Detection

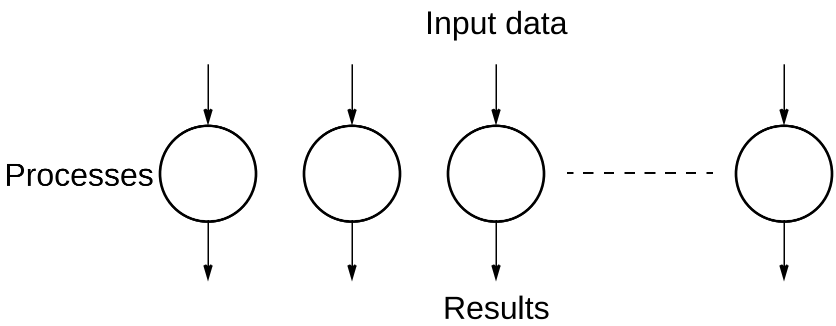
Not covered in 1st edition of textbook

Chapter 3

Embarrassingly Parallel Computations

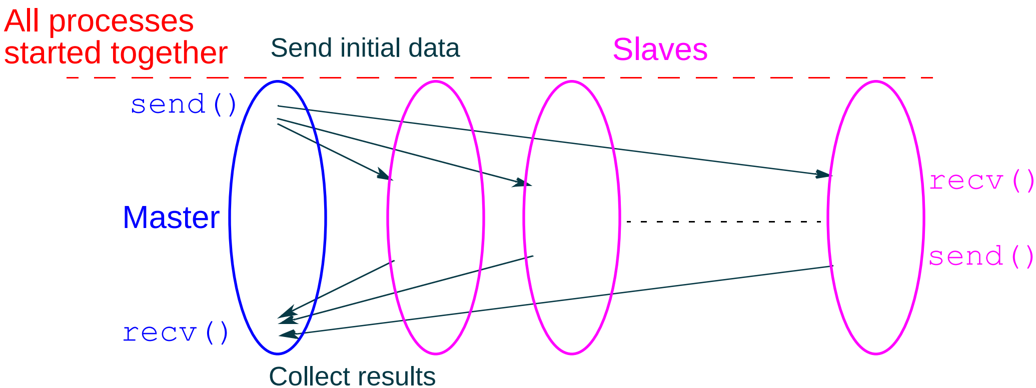
Embarrassingly Parallel Computations

A computation that can obviously be divided into a number of completely independent parts, each of which can be executed by a separate process(or).



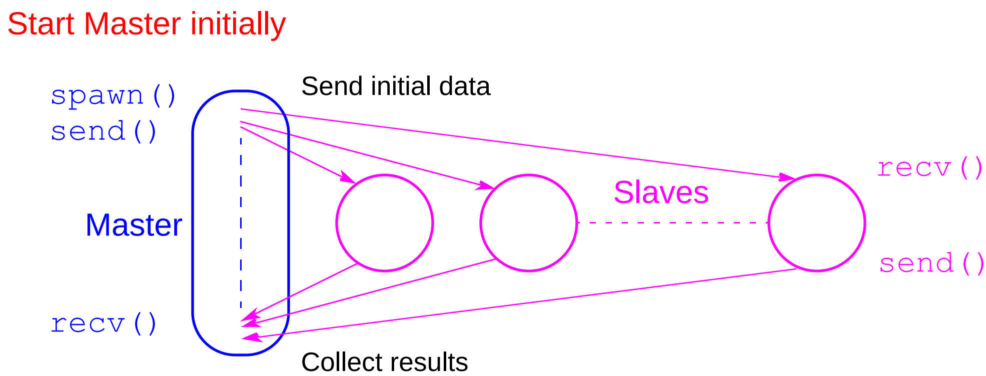
No communication or very little communication between processes
Each process can do its tasks without any interaction with other processes

Practical embarrassingly parallel computation with static process creation and master-slave approach



MPI approach

Practical embarrassingly parallel computation with dynamic process creation and master-slave approach



PVM approach

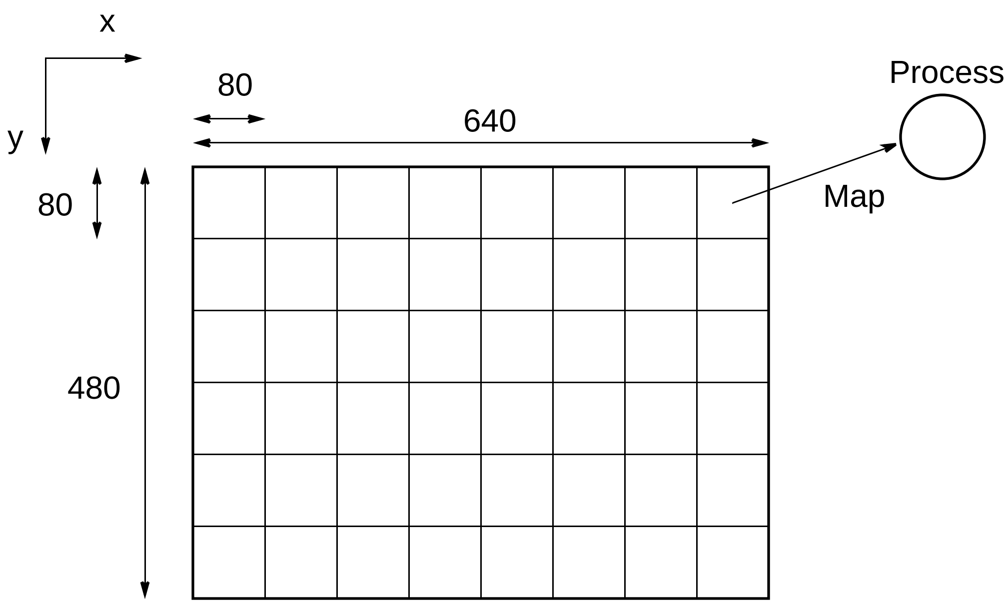
Embarrassingly Parallel Computation Examples

- Low level image processing
- Mandelbrot set
- Monte Carlo Calculations

Low level image processing

Many low level image processing operations only involve local data with very limited if any communication between areas of interest.

Partitioning into regions for individual processes.



Square region for each process (can also use strips)

Some geometrical operations

Shifting

Object shifted by Δx in the x-dimension and Δy in the y-dimension:

$$x' = x + \Delta x$$
$$y' = y + \Delta y$$

where x and y are the original and x' and y' are the new coordinates.

Scaling

Object scaled by a factor S_x in x-direction and S_y in y-direction:

$$x' = xS_x$$
$$y' = yS_y$$

Rotation

Object rotated through an angle θ about the origin of the coordinate system:

$$x' = x\cos\theta + y\sin\theta$$
$$y' = -x\sin\theta + y\cos\theta$$

Mandelbrot Set

Set of points in a complex plane that are quasi-stable (will increase and decrease, but not exceed some limit) when computed by iterating the function

$$z_{k+1} = z_k^2 + c$$

where z_{k+1} is the $(k + 1)$th iteration of the complex number $z = a + bi$ and c is a complex number giving position of point in the complex plane. The initial value for z is zero.

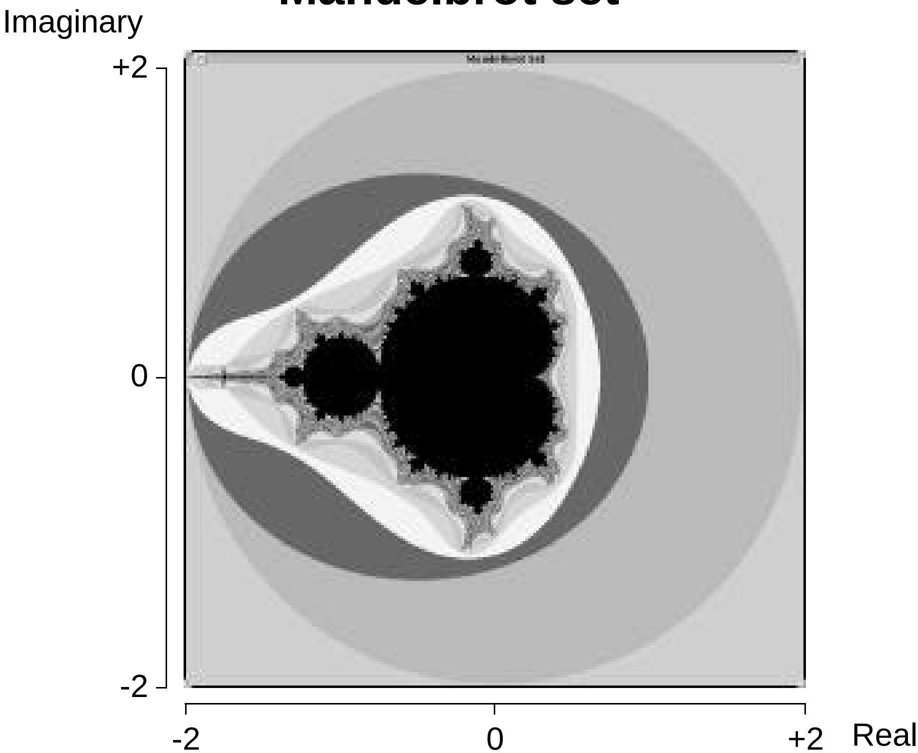
Iterations continued until magnitude of z is greater than 2 or number of iterations reaches arbitrary limit. Magnitude of z is the length of the vector given by

$$z_{\text{length}} = \sqrt{a^2 + b^2}$$

Sequential routine computing value of one point returning number of iterations

```
structure complex {
  float real;
  float imag;
};
int cal_pixel(complex c)
{
int count, max;
complex z;
float temp, lengthsq;
max = 256;
z.real = 0; z.imag = 0;
count = 0;                              /* number of iterations */
do {
  temp = z.real * z.real - z.imag * z.imag + c.real;
  z.imag = 2 * z.real * z.imag + c.imag;
  z.real = temp;
  lengthsq = z.real * z.real + z.imag * z.imag;
  count++;
} while ((lengthsq < 4.0) && (count < max));
return count;
}
```

Mandelbrot set



Slides for *Parallel Programming Techniques and Applications Using Networked Workstations and Parallel Computers* by Barry Wilkinson and Michael Allen, Prentice Hall Upper Saddle River New Jersey, USA, ISBN 0-13-671710-1.

Parallelizing Mandelbrot Set Computation

Static Task Assignment

Simply divide the region in to fixed number of parts, each computed by a separate processor.

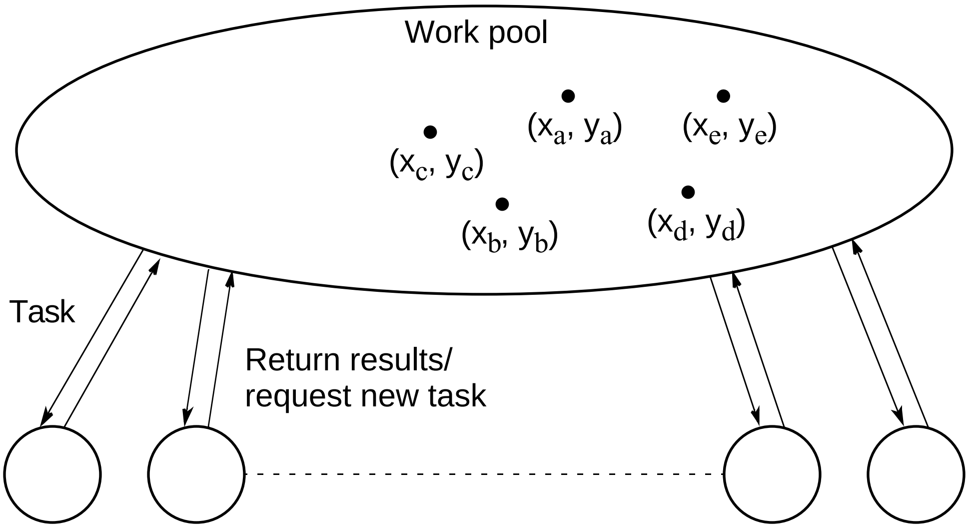
Not very successful because different regions require different numbers of iterations and time.

Dynamic Task Assignment

Have processor request regions after computing previous regions

Dynamic Task Assignment

Work Pool/Processor Farms



Monte Carlo Methods

Another embarrassingly parallel computation.

Monte Carlo methods use of random selections.

Example - To calculate π

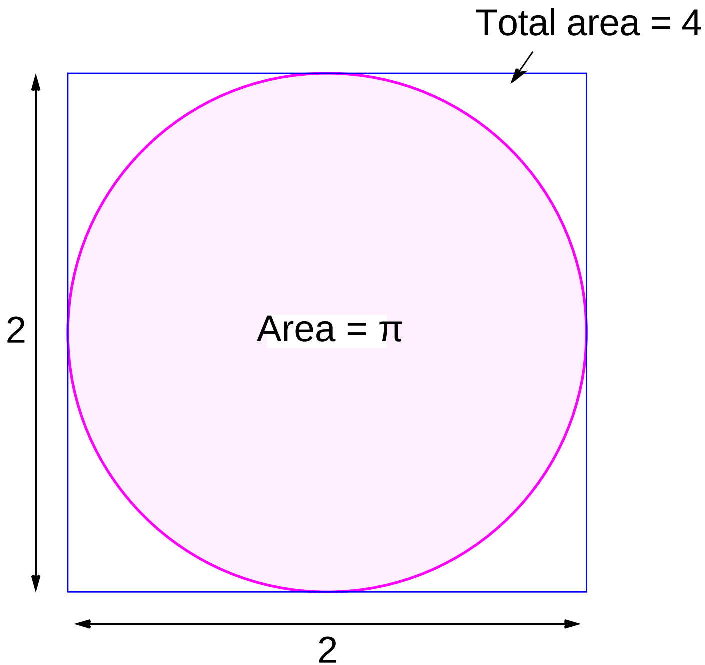
Circle formed within a square, with unit radius so that square has sides 2 × 2. Ratio of the area of the circle to the square given by

$$\frac{\text{Area of circle}}{\text{Area of square}} = \frac{\pi(1)^2}{2 \times 2} = \frac{\pi}{4}$$

Points within square chosen randomly.

Score kept of how many points happen to lie within circle.

Fraction of points within the circle will be $\pi/4$, given a sufficient number of randomly selected samples.


Total area = 4
Area = π
2
2

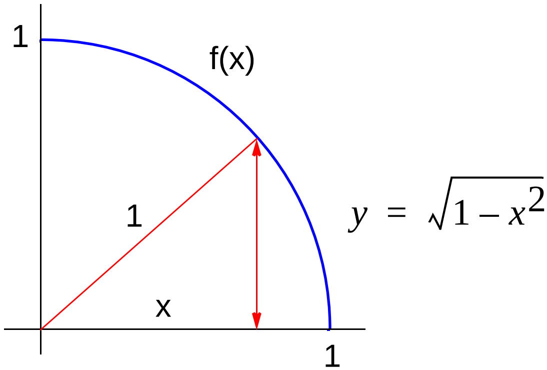
Computing an Integral

One quadrant of the construction can be described by integral

$$\int_0^1 \sqrt{1-x^2}\,dx = \frac{\pi}{4}$$

Random pairs of numbers, (x_r, y_r) generated, each between 0 and 1.

Counted as in circle if $y_r \le \sqrt{1-x_r^2}$; that is, $y_r^2 + x_r^2 \le 1$.



Alternative (better) Method

Use random values of *x* to compute *f*(*x*) and sum values of *f*(*x*):

$$\text{Area} = \int_{x_1}^{x_2} f(x)\,dx = \lim_{N \to \infty} \frac{1}{N} \sum_{i=1}^{N} f(x_r)(\mathrm{x}_2 - \mathrm{x}_1)$$

where x_r are randomly generated values of x between x_1 and x_2.

Monte Carlo method very useful if the function cannot be integrated numerically (maybe having a large number of variables)

Prentice Hall Upper Saddle River New Jersey, USA, ISBN 0-13-671710-1.

Example

Computing the integral

$$I = \int_{x_1}^{x_2} (x^2 - 3x)\, dx$$

Sequential Code

```
sum = 0;
for (i = 0; i < N; i++) {  /* N random samples */
    xr = rand_v(x1, x2);    /* generate next random value */
    sum = sum + xr * xr - 3 * xr;     /* compute f(xr) */
}
area = (sum / N) * (x2 - x1);
```

Routine randv(x1, x2) returns a pseudorandom number between x1 and x2.

For parallelizing Monte Carlo code, must address best way to generate random numbers in parallel - see textbook

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