Delivering Interactive
Parallel Computing Power
to the Desktop

sgi

An Interactive Approach to Parallel Combinatorial Algorithms with Star-P

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Parallel Computing Arts

Message Passing:

The King's Messenger

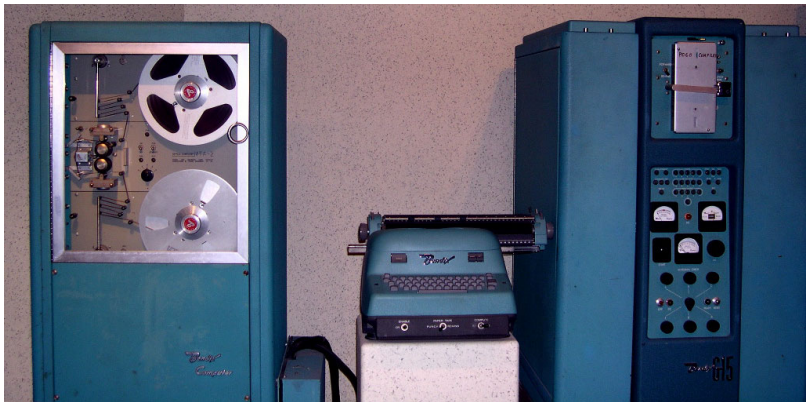
Batch Processing:

Coding, Modeling, & Debugging

Punch Cards (textile loom 1840)

Noble perfected arts: what's next for productivity?

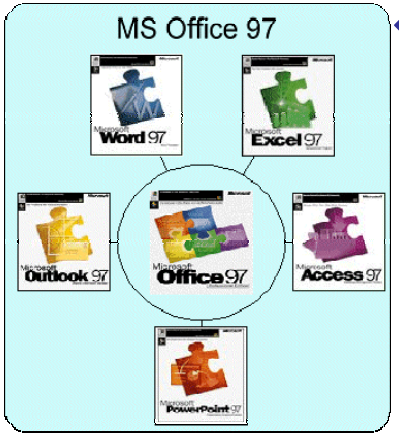
Productivity



← Make this machine go faster?

Most important catalysts for productivity are

Interactivity & ease of use



←puzzle pieces working together

Humans interacting online→

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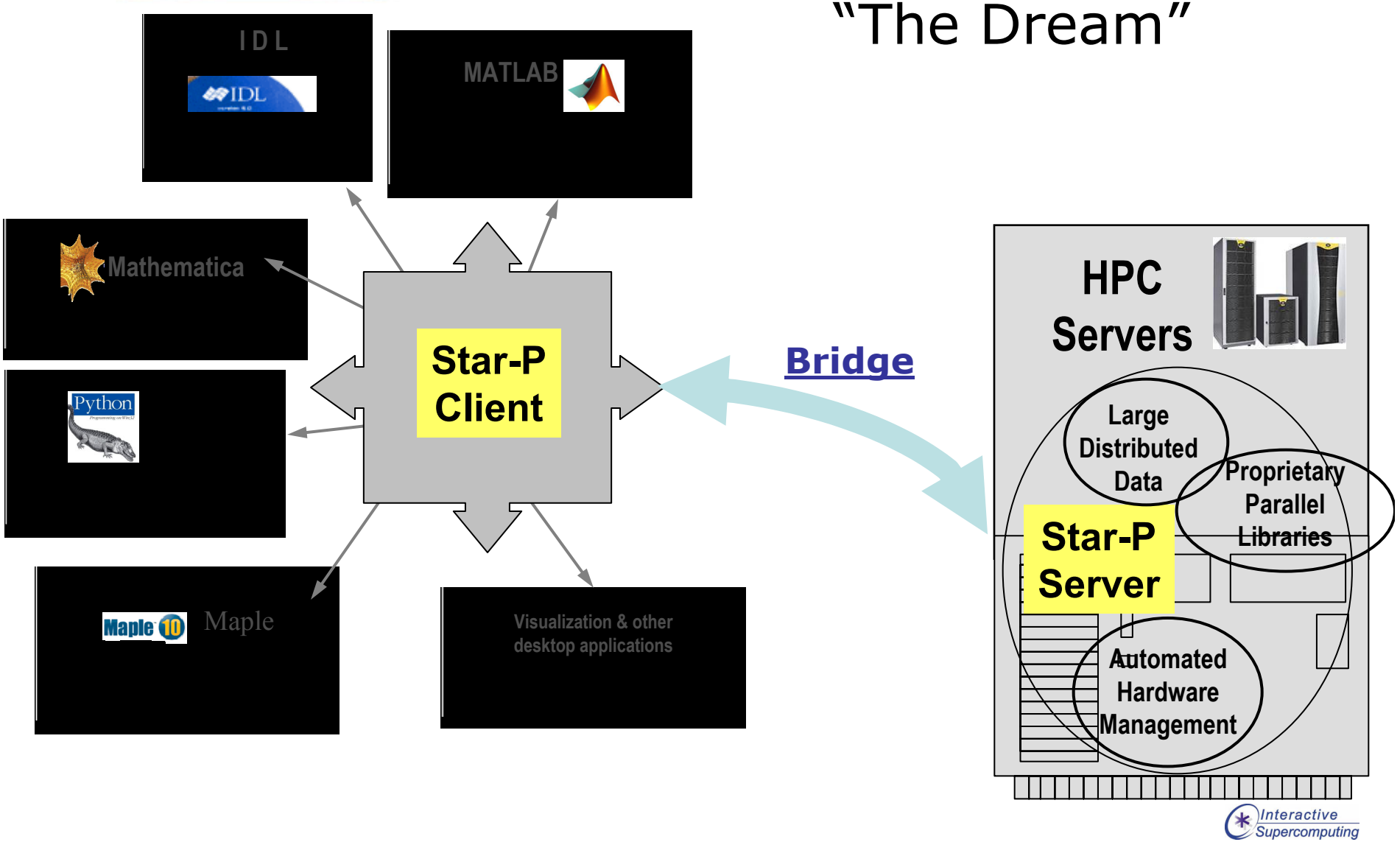
Star-P = A Software Platform For Interactive Supercomputing

"The Dream"



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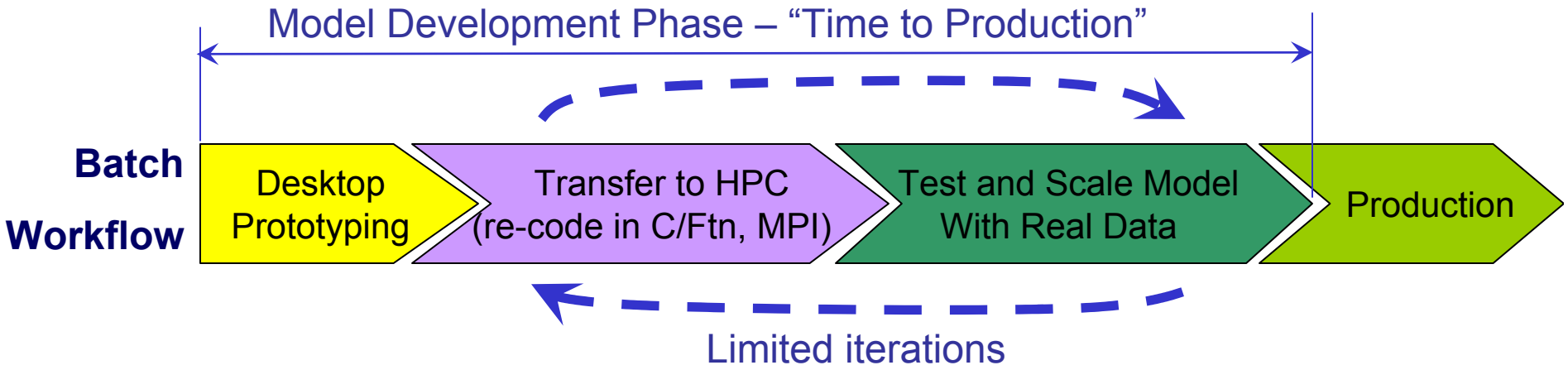
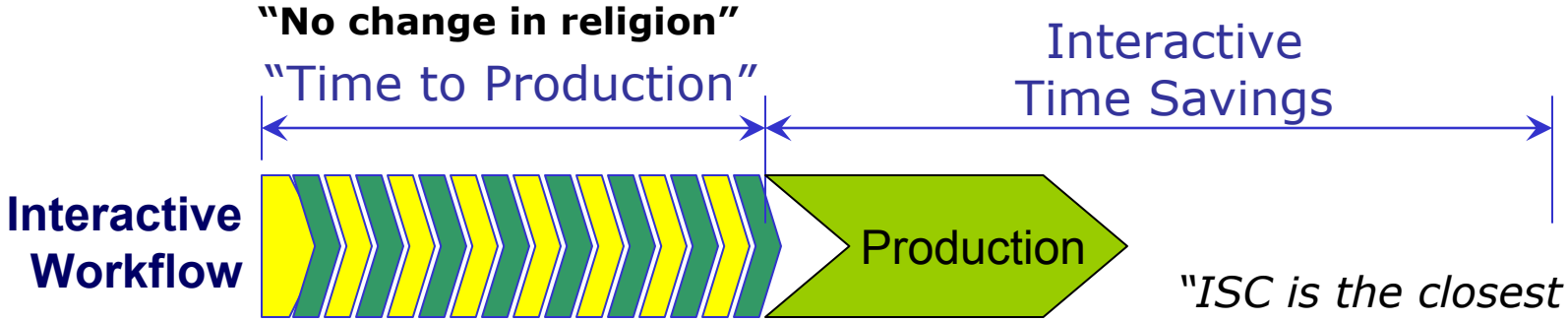
INTERACTIVE Fundamentally Alters the Flawed Process

Re-coding takes time, and invariably takes away from model refinement



"No change in religion"



"ISC is the closest thing I've seen to a killer app." **John Mucci**
CEO, SiCortex

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High Productivity Design Principles

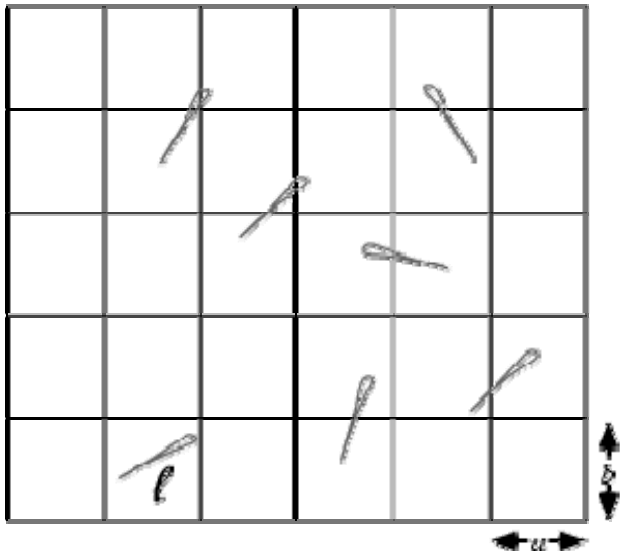
1. **Rich set of High Performance primitives & tools.**
   a. Interoperate
   b. Interactive

2. **OK to exploit special-purpose hardware as appropriate (FGPGAs, GPUs)**

3. **Do it yourself (in MPI, OpenMP, etc.,) → do it for everyone!**

StarP with MATLAB®

The Buffon Needle Problem



$$P(l;a,b)=(2l(a+b)-l^2) / (\pi ab)$$

```
function z=buffon(a,b,l, trials)
    %% Embarassingly Parallel Part
    r=rand(trials,3);
    x =a*r(:,1)+l*cos(2*pi*r(:,3));  % x coord
    y =b*r(:,2)+l*sin(2*pi*r(:,3));  % y coord

    inside = (x >= 0) & (y>=0) & (x <= a) & (y <= b);


    %% Collective Operation (the sum)
    bpi=(2*l*(a+b) - l^2)/ (a*b*(1-sum(inside)/trials));

    %%  Front end
    z=[buffonpi;pi;abs(pi-buffonpi)/pi];
```

buffon(1,1,.5,10000*p)

Star-P Language

1. MATLAB™, plus
2. global view (*v.* node-oriented)
3. Strong bias towards propagation of distributed attribute
4. *p denotes dimension of distributed array
5. Overloading of operators
6. ppeval for task parallelism

7. Empirical data: typically have to change 10-20 SLOC for MATLAB codes to work in Star-P

```
xxx == explicit parallel extension
yyy == parallelism propagated
       implicitly

a = rand(n,n*p);
ppload imagedata a

[nrow ncol] = size(a);
b = ones(nrow,ncol);
c = fft2(a);
d = ifft2(c);

diff = max(max(abs(a-d)));
if (diff > 10*eps)
   sprintf('Error, diff=%f', diff);
end

e = ppeval('sum',a);
e = ppeval('quad','fun',a);
```

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Combinatorial Algorithm Design Principle: Do it with a sparse matrix

Graph Operations are well expressed with sparse matrices as the data structure.

Primitives for combinatorial scientific computing.

a. Random-access indexing: `A(i,j)`

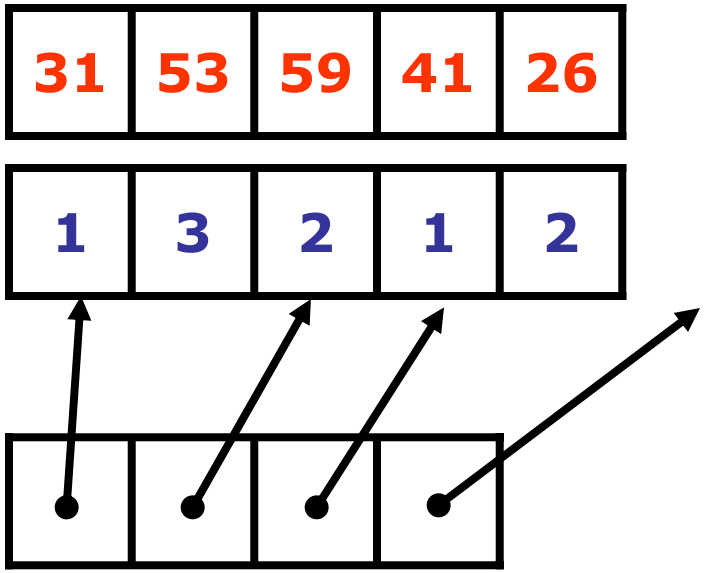
b. Neighbor sequencing: `find (A(i,:))`

c. Sparse table construction: `sparse (I, J, V)`

d. Matrix * Vector: walking on the graph

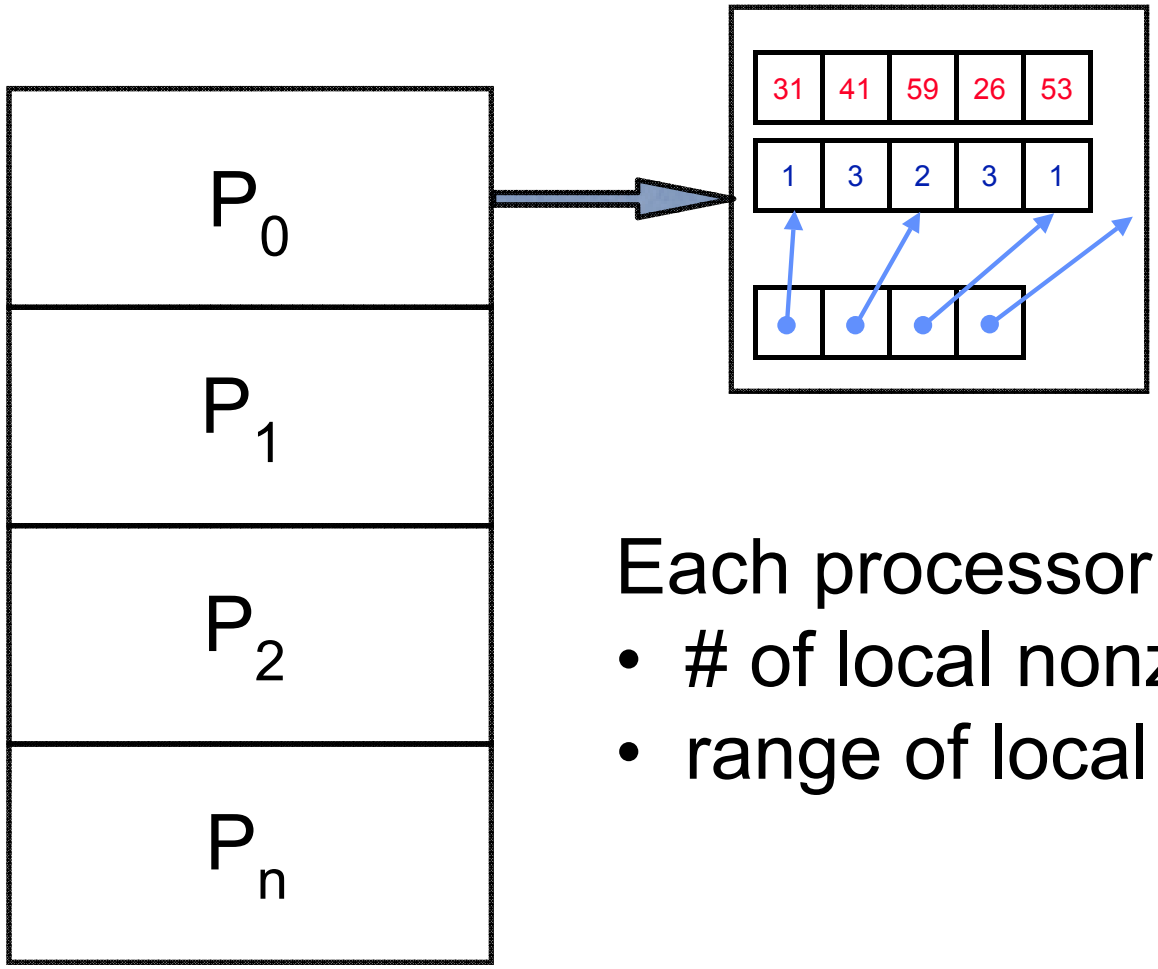
Star-P sparse data structure

31	0	53
0	59	0
41	26	0



- Full:
  - 2-dimensional array of real or complex numbers
  - (nrows*ncols) memory
- Sparse:
  - compressed row storage
  - about (2*nzs + nrows) memory

Star-P distributed sparse data structure



Each processor stores:

- # of local nonzeros
- range of local rows

SSCA#2 Graph Theory Benchmark

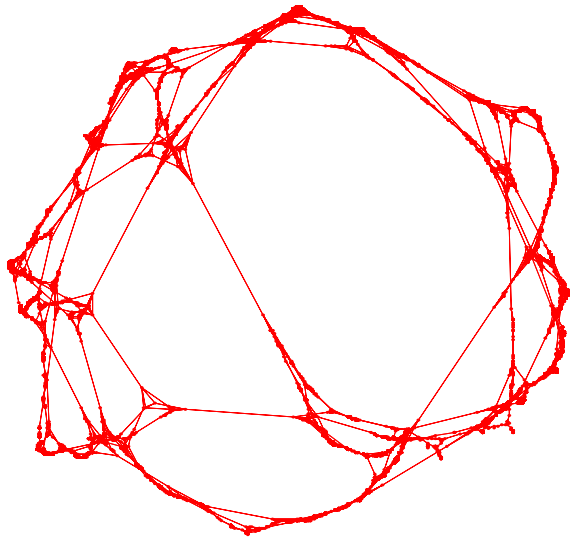
HPCS High Productivity Computer Systems

Scalable Synthetic Compact Application (SSCA) Benchmarks

1. **Bioinformatics Optimal Pattern Matching**
2. **Graph Theory**
3. **Sensor Processing**

SSCA#2:- Graph Analysis; stresses memory access; compute-intensive and hard to parallelize.

8192-vertex graph from Kernel 1 plotted with Fiedler coordinates



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SSCA#2

Kernel 1: Construct graph data structures

Bulk of time for smaller problems

Kernel 2: Search within large sets

Kernel 3: Subgraph extraction

Kernel 4: Graph clustering

Version does not scale for larger problems

OpenMP Contest:

http://www.openmp.org/drupal/sc05/omp-contest.htm

1.First prize: $1000 plus a 60GB iPod.

2.Second prize: $500 plus a 4GB iPod nano.

3.Third prize: $250 plus a 1GB iPod shuffle

Scalability

Kernels 1 through 3 ran on $N=2^{26}$

- Previous largest known run is $N=2^{21}$ or 32 times smaller on a Cray MTA-2

- Timings scale reasonably – we played with building the largest sparse matrix we could, until we hit machine limitations!
  - 2xProblem Size → 2xTime
  - 2xProblem Size & 2xProcessor Size → same time

Lines of Code

Lines of executable code (excluding I/O and graphics based on original codes available):

	cSSCA2	The spec	Pthreads
Kernel 1	29	68	256
Kernel 2	12	44	121
Kernel 3	25	91	297
Kernel 4	44	295	241

Expressive Power: SSCA#2 Kernel 3

Star-P (25 SLOC)

```
A = spones(G.edgeWeights{1});
nv = max(size(A));
npar = length(G.edgeWeights);
nstarts = length(starts);
for i = 1:nstarts
    v = starts(i);
    % x will be a vector whose nonzeros
    % are the vertices reached so far
    x = zeros(nv,1);
    x(v) = 1;
    for k = 1:pathlen
        x = A*x;
        x = (x ~= 0);
    end;
    vtxmap = find(x);
    S.edgeWeights{1} = G.edgeWeights{1}…
        (vtxmap,vtxmap);
    for j = 2:npar
        sg = G.edgeWeights{j}(vtxmap,vtxmap)
        if nnz(sg) == 0
            break;
        end;
        S.edgeWeights{j} = sg;
    end;
    S.vtxmap = vtxmap;
    subgraphs{i} = S;
end
```

MATLABmpi (91 SLOC)

```
declareGlobals;


intSubgraphs = subgraphs(G, pathLength, startSetInt);
strSubgraphs = subgraphs(G, pathLength, startSetStr);

%| Finish helping other processors.
if P.Ncpus > 1
  if P.myRank == 0              % if we are the leader
    for unused = 1:P.Ncpus-1
      [src tag] = probeSubgraphs(G, [P.tag.K3.results]);
      [isg ssg] = MPI_Recv(src, tag, P.comm);
      intSubgraphs = [intSubgraphs isg];
      strSubgraphs = [strSubgraphs ssg];
    end
    for dest = 1:P.Ncpus-1
      MPI_Send(dest, P.tag.K3.done, P.comm);
    end
  else
    MPI_Send(0, P.tag.K3.results, P.comm, ...
        intSubgraphs, strSubgraphs);
    [src tag] = probeSubgraphs(G, [P.tag.K3.done]);
    MPI_Recv(src, tag, P.comm);
  end
end


function graphList = subgraphs(G, pathLength, startVPairs)

graphList = [];

% Estimated # of edges in a subgraph. Memory will grow as needed.
estNumSubGEdges = 100;  % depends on cluster size and path length

%-------------------------------------------------------------------------
% Find subgraphs.
%-------------------------------------------------------------------------

% Loop over vertex pairs in the starting set.
for vertexPair = startVPairs.'
```

```
    % Wait for a response for each request we sent out.
    for unused = 1:numRqst
      [src tag] = probeSubgraphs(G, [P.tag.K3.dataResp]);
      [starts newEdges] = MPI_Recv(src, tag, P.comm);
      subg.edgeWeights{1}(:, starts) = newEdges;
      [newEnds unused] = find(newEdges);
      allNewEnds = [allNewEnds; newEnds];
    end
  end % of if ~P.paral

  % Eliminate any new ends already in the all starts list.
  newStarts = setdiff(allNewEnds.', allStarts);
  allStarts = [allStarts newStarts];

  if ENABLE_PLOT_K3DB
    plotEdges(subg.edgeWeights{1}, startVertex, endVertex, k);
  end % of ENABLE_PLOT_K3DB

  if isempty(newStarts)        % if empty we can quit early.
    break;
  end
end

  % Append to array of subgraphs.
  graphList = [graphList subg];
end
                function [src, tag] = probeSubgraphs(G, recvTags)


while true
  [ranks tags] = MPI_Probe('*', P.tag.K3.any, P.comm);
  requests = find(tags == P.tag.K3.dataReq);
  for mesg = requests.'
    src = ranks(mesg);
    starts = MPI_Recv(src, P.tag.K3.dataReq, P.comm);
    newEdges = G.edgeWeights{1}(:, starts - P.myBase);
    MPI_Send(src, P.tag.K3.dataResp, P.comm, starts, newEdges);
  end
```

	cSSCA2	executable spec	C/Pthreads/ SIMPLE
Kernel 1	**29**	**68**	**256**
Kernel 2	**12**	**44**	**121**
Kernel 3	**25**	**91**	**297**
Kernel 4	**44**	**295**	**241**

```
uniqDests = unique(startDests);
for dest = uniqDests
  starts = newStarts(startDests == dest);

  if dest == P.myRank
    newEdges = G.edgeWeights{1}(:, starts - P.myBase);
    subg.edgeWeights{1}(:, starts) = newEdges;
    [allNewEnds unused] = find(newEdges);
  elseif ~isempty(starts)
    MPI_Send(dest, P.tag.K3.dataReq, P.comm, starts);
    numRqst = numRqst + 1;
```

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Interactivity!

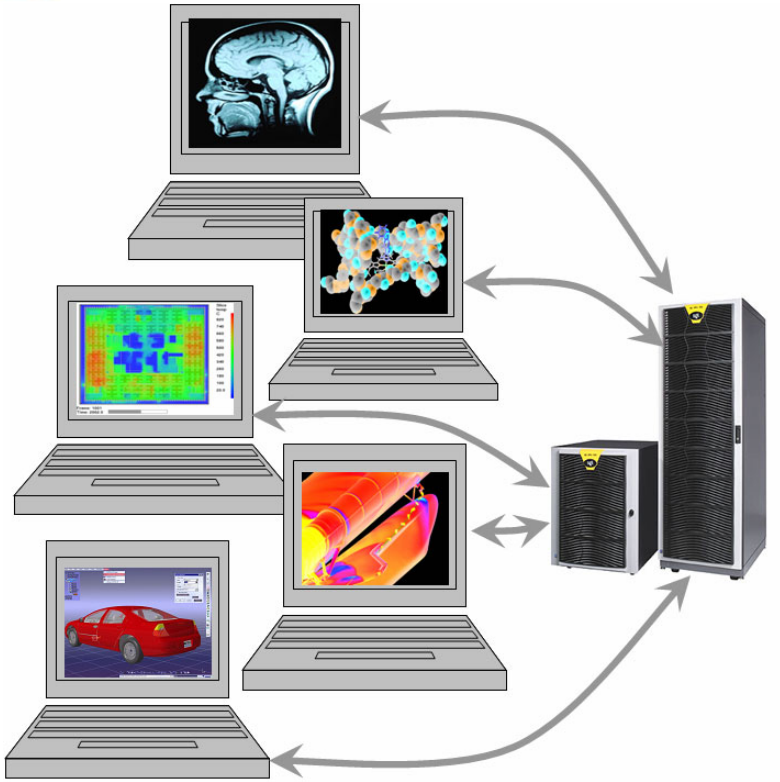
Did not just build a benchmark: Explored an algorithm space!

Spectral Partitioning based on Parpack was fine for small sizes but not larger.

We played around! We plotted data! We had a good time. ☺ Parallel computing is fun again!

Interactive Supercomputing

1. **No "change in religion"**
   a. Use familiar tools
   b. Desktop, interactive
2. **5-10x manpower savings by transforming workflow**
   a. Enables rapid (and more frequent) iteration
   b. Drives better conclusions, decisions, products
3. **Improves "Time to Production"**
   a. 50% reductions in calendar time
   b. Improves time to market
   c. Increases profits



"In computing with humans, response time is everything….One's likelihood of getting the science right falls quickly as one loses the ability to steer the computation on a human time scale."

Prof. Nick Trefethen
Oxford University

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