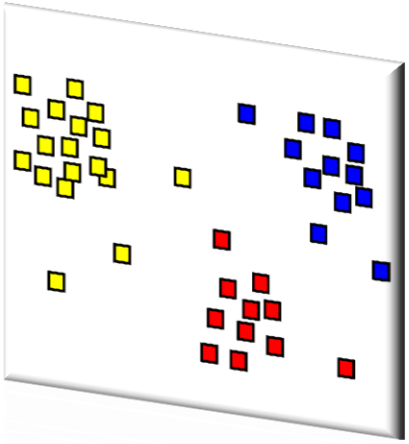
CloudClustering

Toward a scalable machine learning toolkit for Windows Azure



Ankur Dave

XCG Intern

Microsoft Research

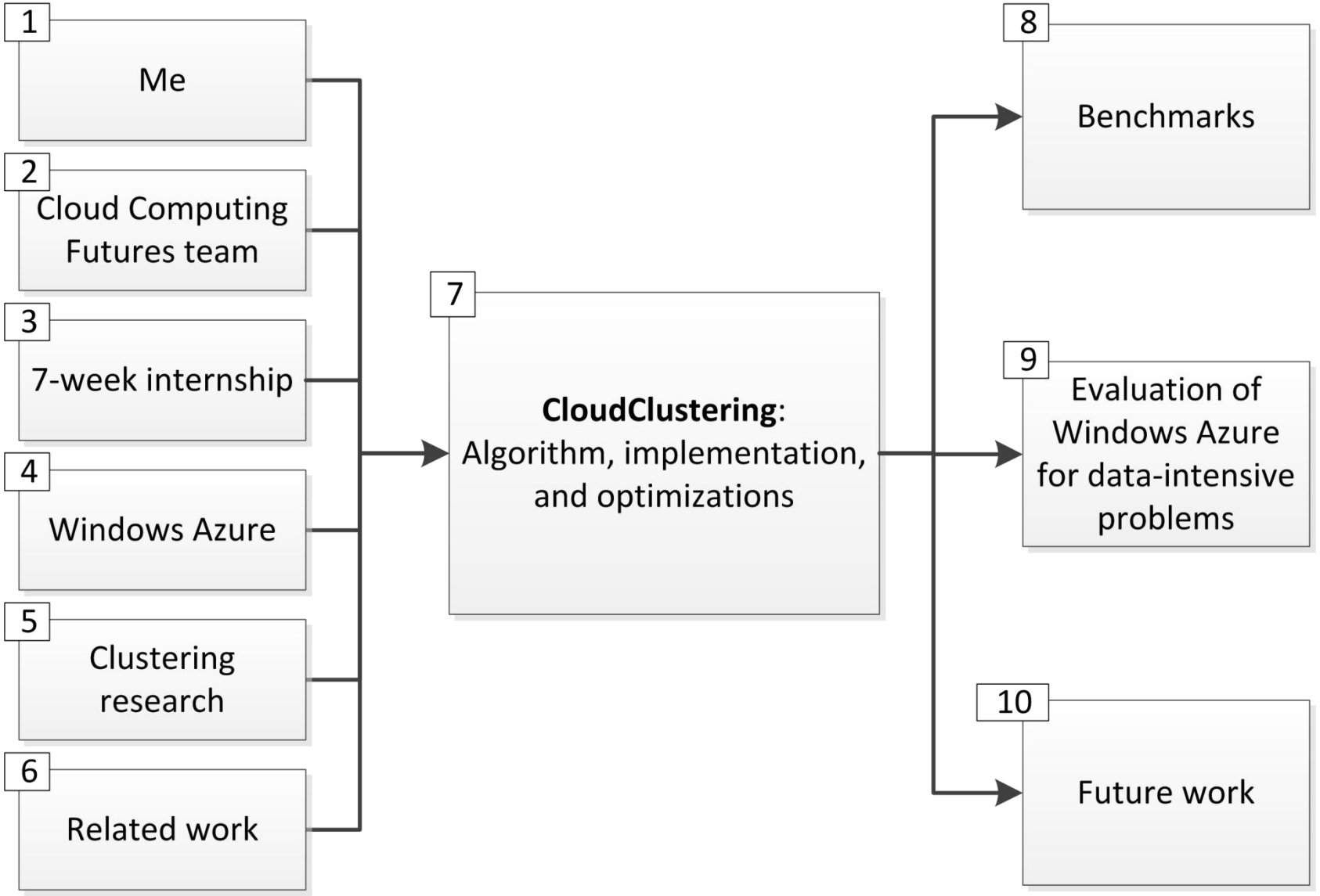
Mentors:

Roger Barga

Wei Lu

August 12, 2010

Agenda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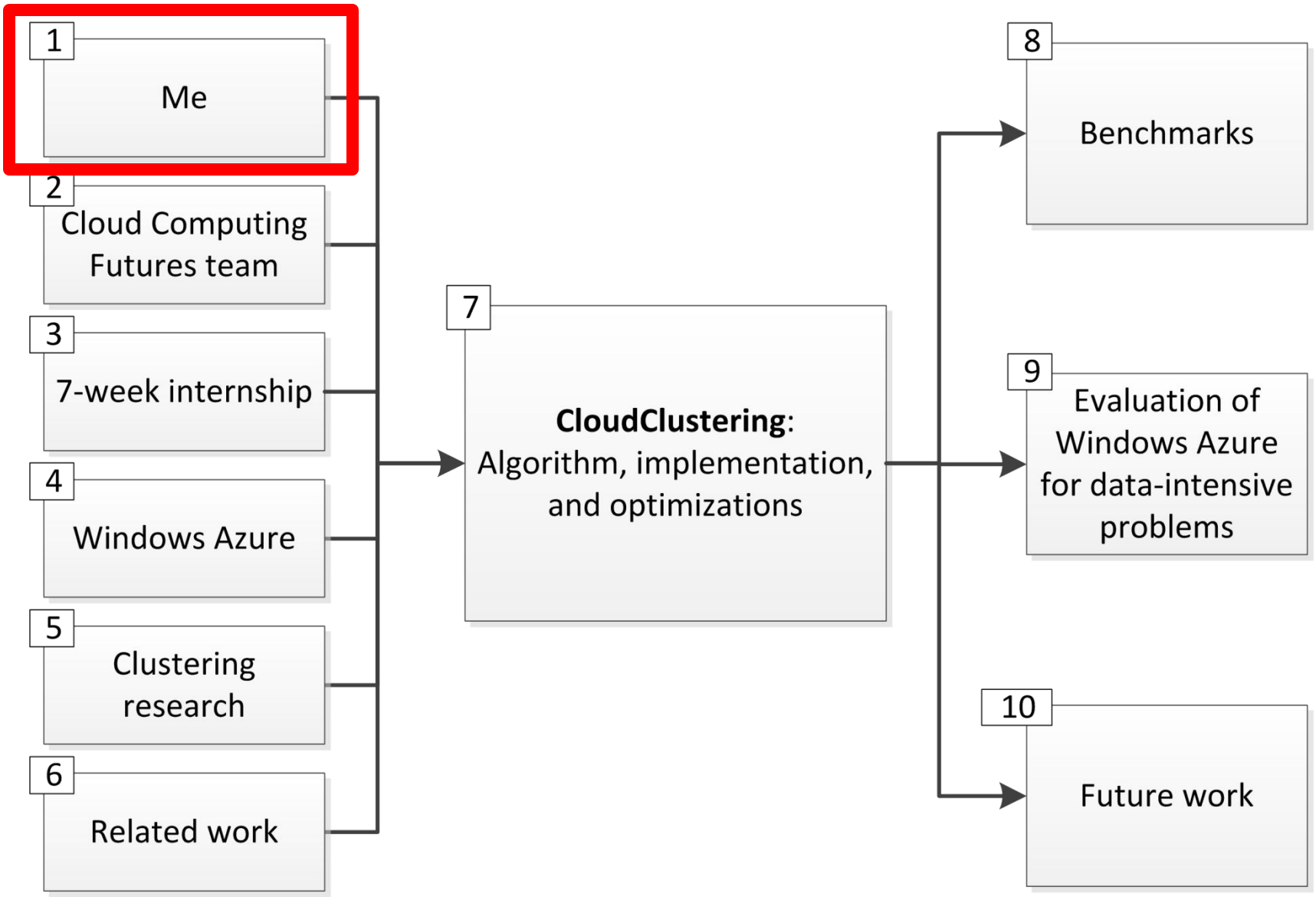
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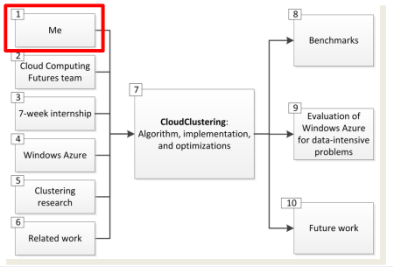
About me



Education

Interlake High School

University of California, Berkeley

Work

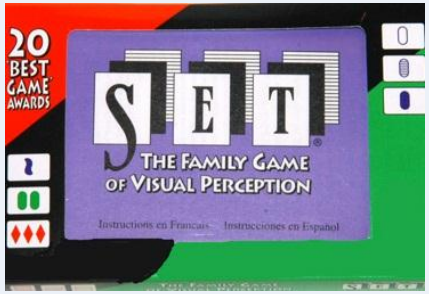
Berkman
The Berkman Center for Internet & Society at Harvard University

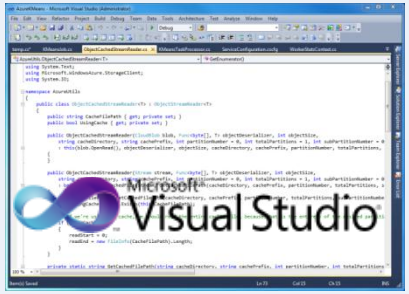
DreamBox Learning

Jain Foundation Inc

CH2MHILL

Hobbies





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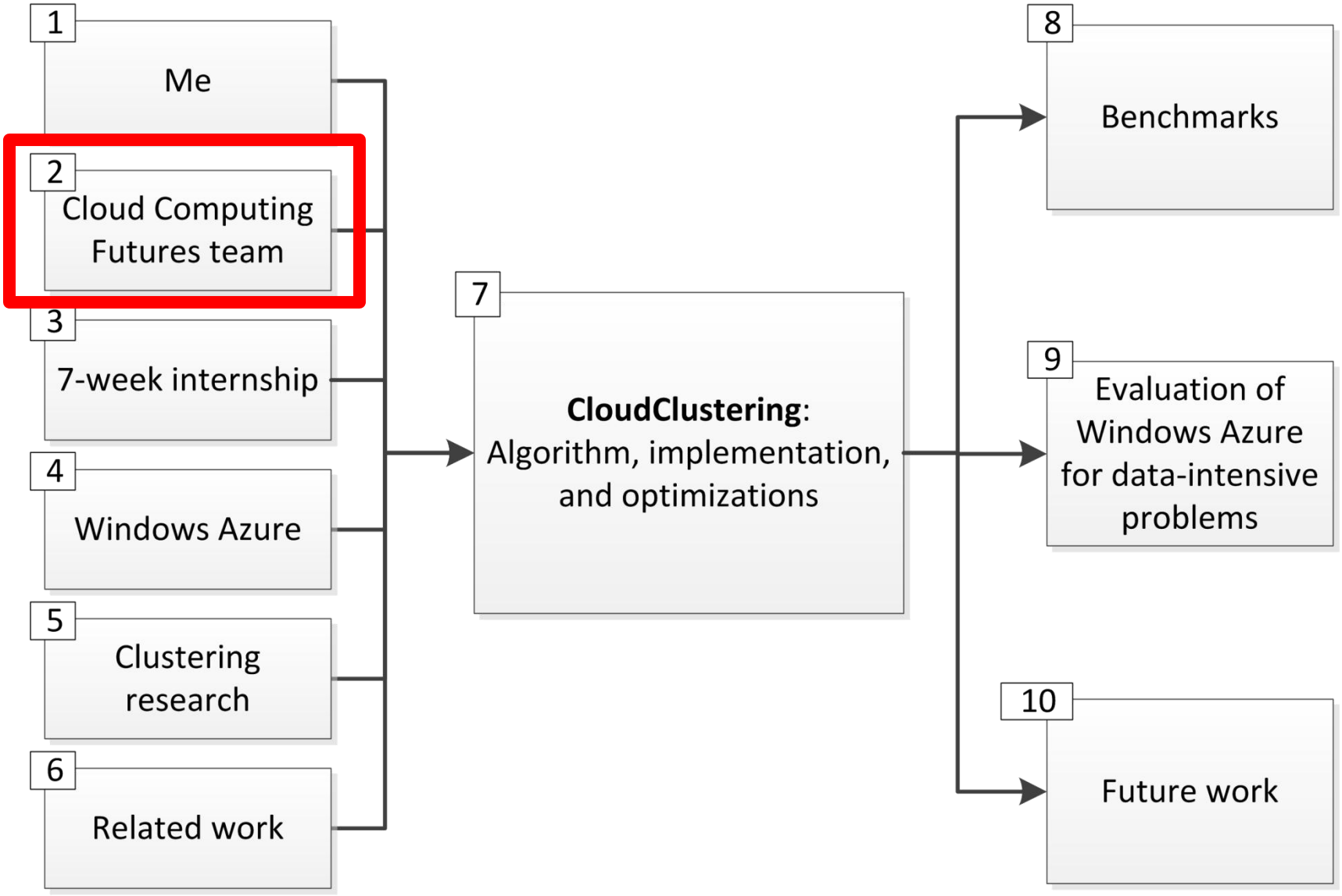
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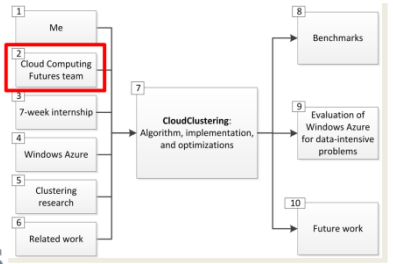
My team



Microsoft® Research

EXTREME COMPUTING GROUP

Cloud Computing Futures

To create novel data center solutions, designs must be based on comprehensive optimization of all attributes, rather than gradually accruing incremental changes based on current technologies and best practices. The Cloud Computing Futures team is tasked to invent on a large scale. Our goal is to reduce data center costs by four-fold or greater, including power consumption, while accelerating deployment and increasing adaptability and resilience to failures.

Azure Research Engagement

The Azure Research Engagement project aims to change the paradigm for scholarly and scientific research by extending the power of the computer into the cloud. We build the components of cloud technology and work with researchers in the field on projects that push the frontier of client and cloud computing.


Dan Reed


Dennis Gannon


Jaliya Ekanayake

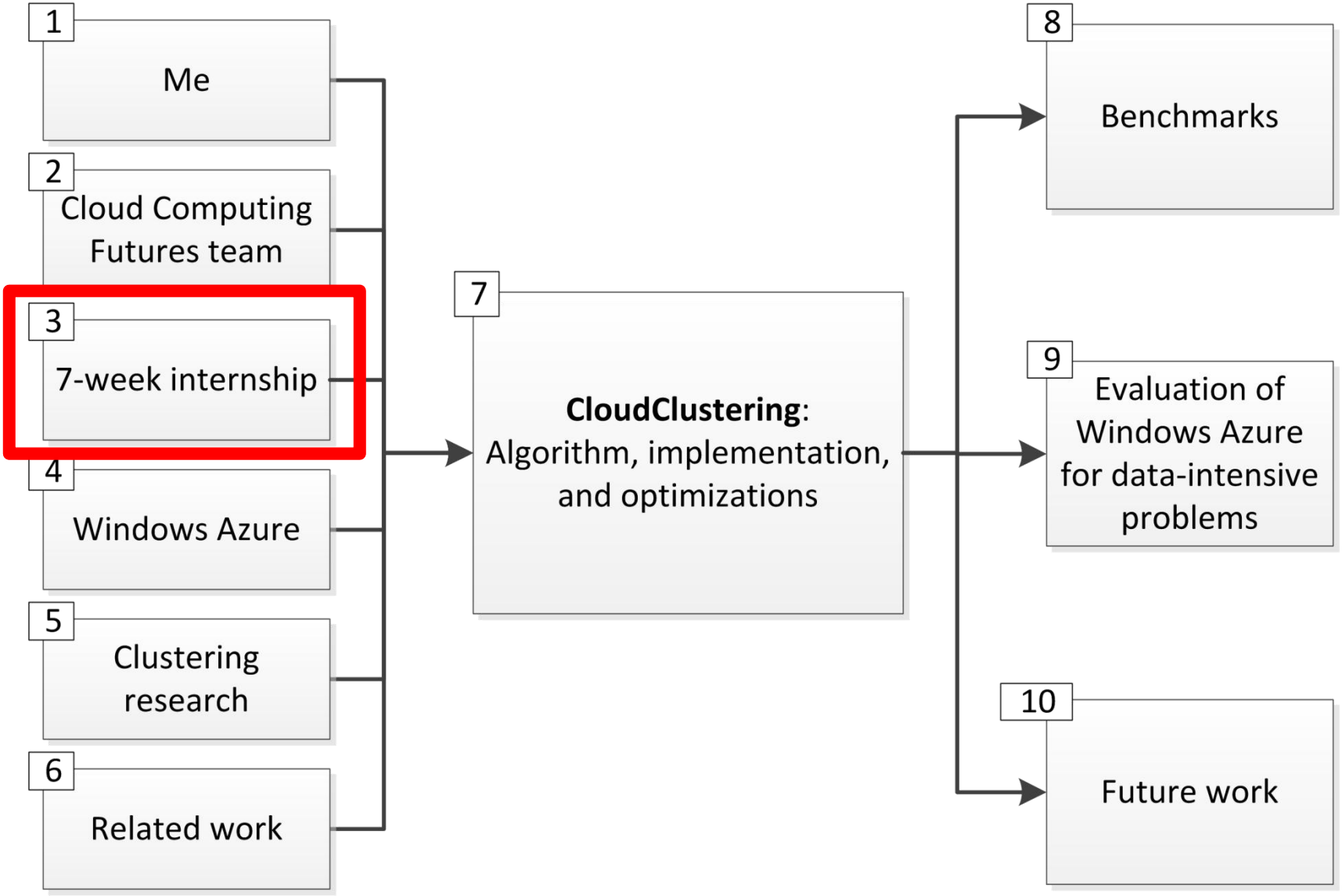

Jared Jackson


Nelson Araujo


Roger Barga


Wei Lu

Agenda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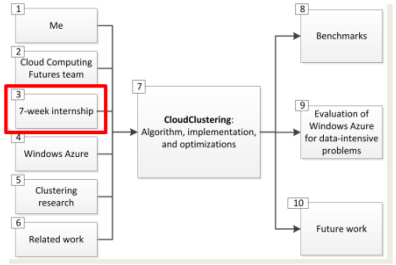
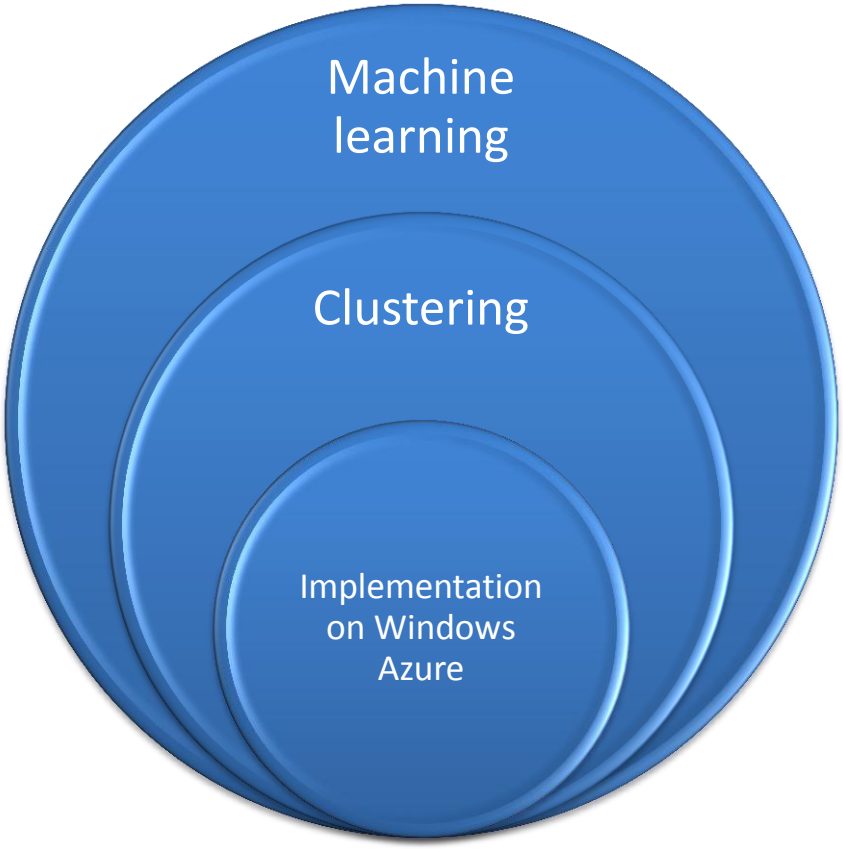
Internship: Domain





Goals:

- Build a scalable clustering algorithm on Azure
- Explore clustering and the cloud by reading papers
- Meet a variety of researchers at MSR

Week 1: Ramp-up; architecture planning

Week 2: Building CloudClustering base impl.

Week 3: Building CloudClustering base impl.

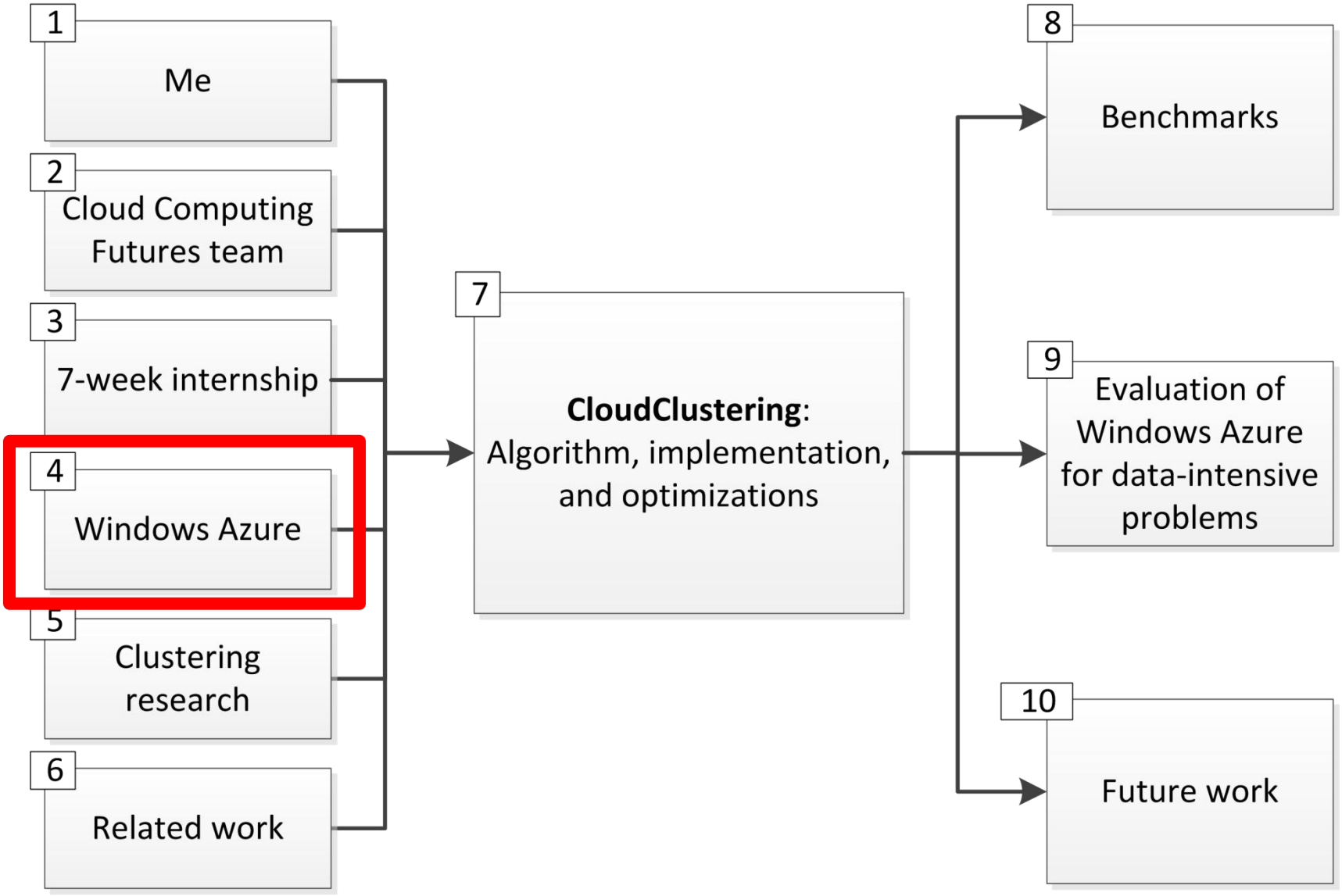
Week 4: Multicore parallelism with PLINQ

Week 5: Performance testing on Azure fabric

Week 6: Multicore w/threads; data affinity

Week 7: Presentation and report-out

Agenda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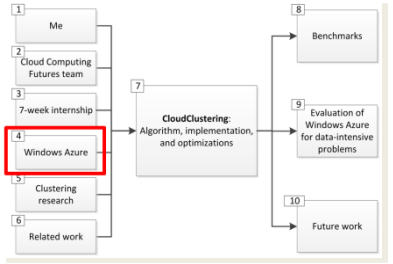
Windows Azure

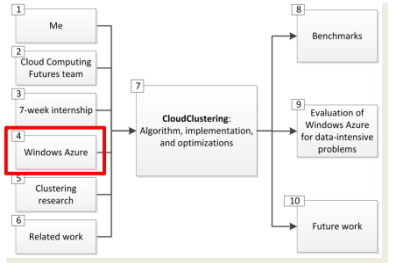


Exploring

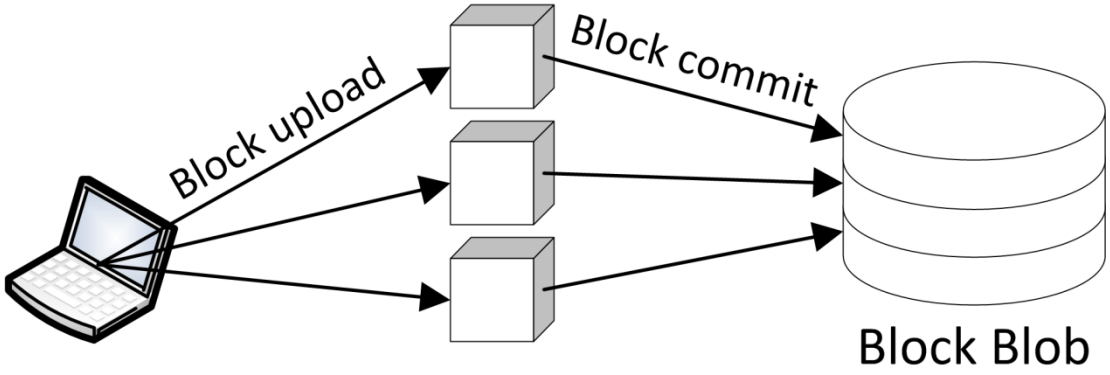
Windows® Azure™

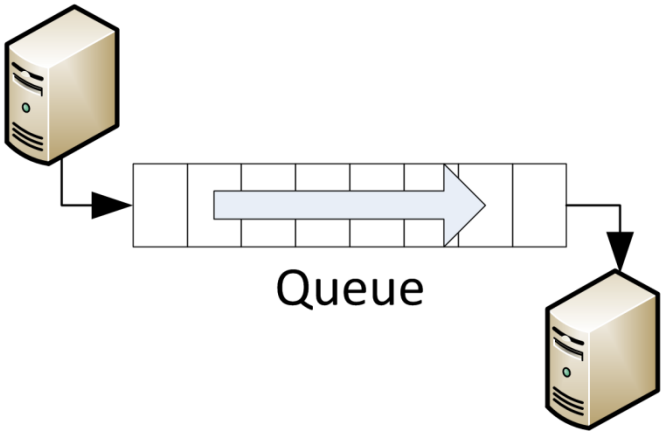
for data-intensive research

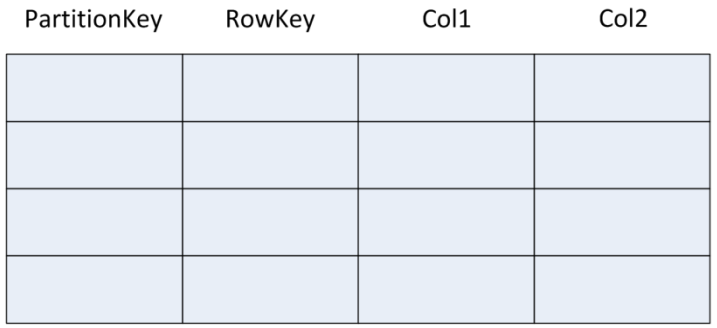
Windows Azure



Instance







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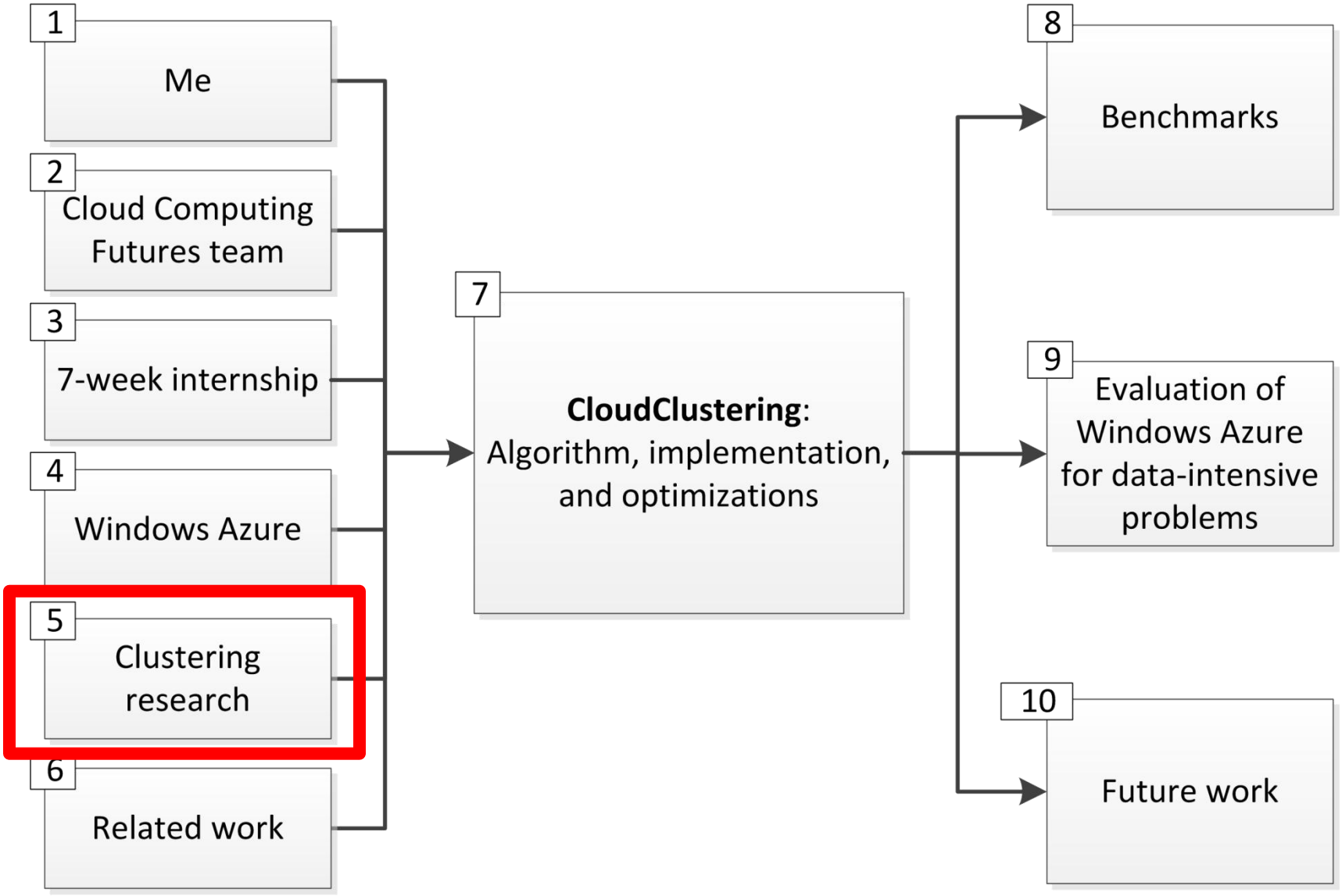
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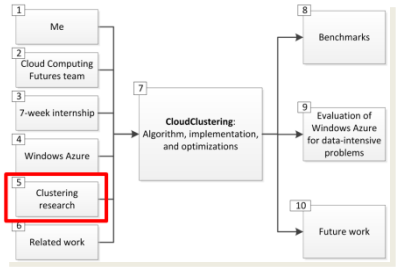
Clustering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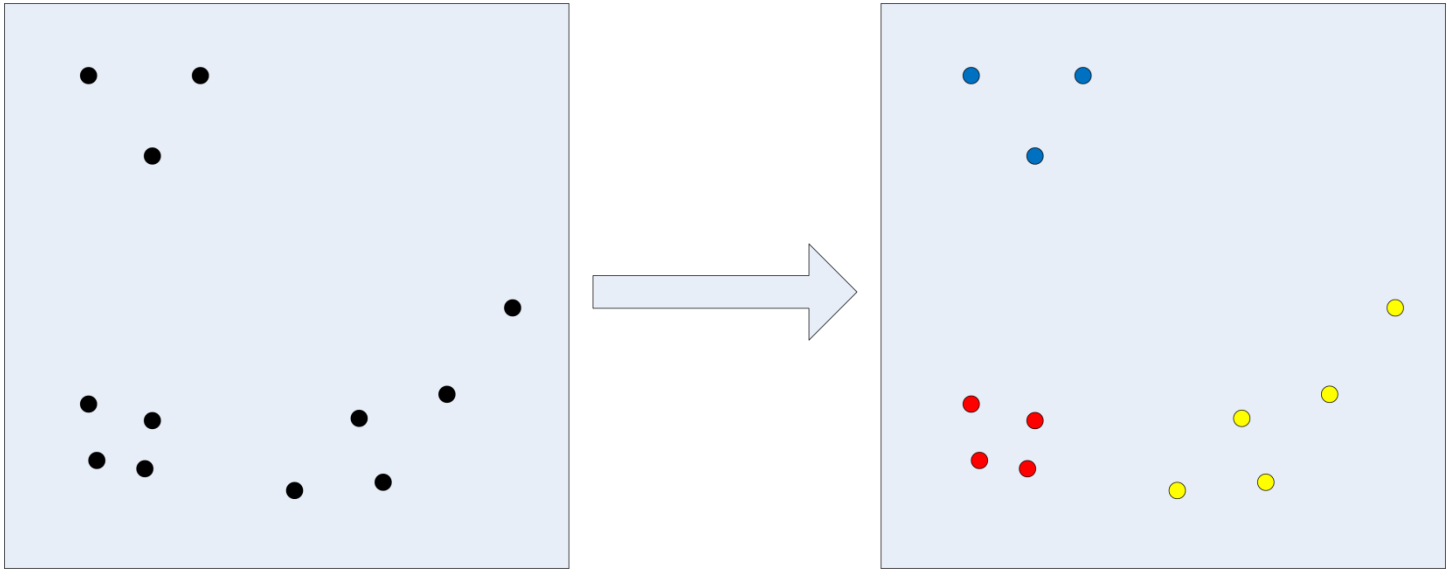
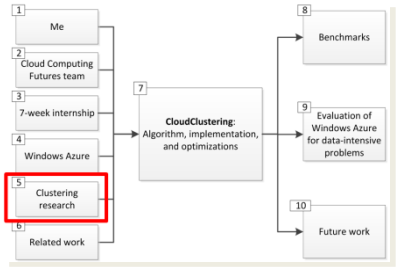


Clustering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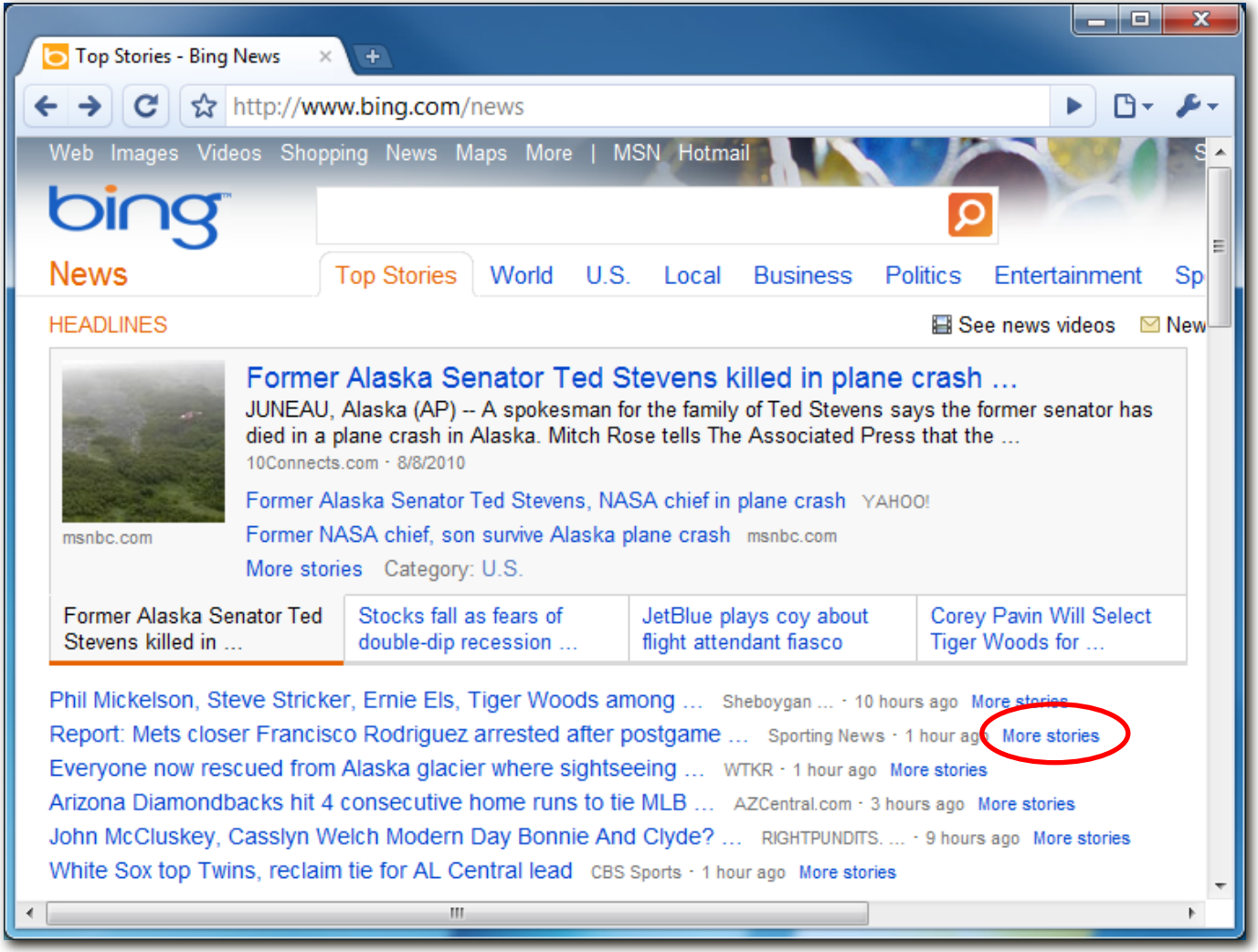
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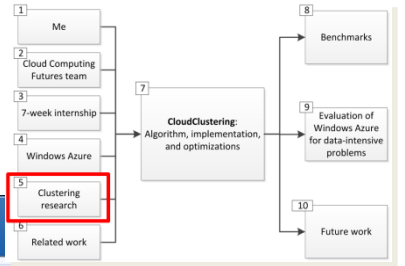

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STORY AT A GLANCE

Tiger Woods has leading role in golf's soap opera
Burlington County Times · 6 hours ago

Fans are coming out in droves to catch a glimpse of their favorite players at the PGA championship. WISN.com · 17 hours ago Read article

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Washington Post

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Usual suspects are suspect at the PGA Championship
Whistling and Straits barely rank among the popular buzzwords this week. Getting far more play: "mosquitoes," " arthritis ," "Jim Gray" and "wide open." The "wide open" part reflects the winners of the last ...
Los Angeles Times · 11 minutes ago

2010 PGA Championship: Ranking Phil Mickelson and Tiger Woods' Chances
The 92 nd PGA Championship is upon us. The 2010 edition sees a return to Whistling Straits for the first time since 2004, when Vijay Singh took home the Wanamaker trophy. And there is no shortage of story lines this year ...
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Phil Mickelson, Steve Stricker, Ernie Els, Tiger Woods among favorites to win PGA ...
Why he can win: Desperately wants to become No. 1 in the world and can do so this week. Long hitter who can overpower one of the longest major championship courses and has the short game to match. Played well ...
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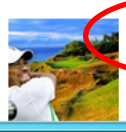

Tiger Woods, Phil Mickelson have much at stake at PGA Championship for different reasons
Articles Tiger Woods struggles continue at Bridgestone Invitational with 75; likely to lose No. 1 ranking Phil Mickelson enters final events of season with

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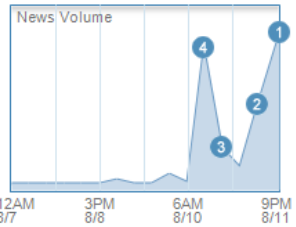

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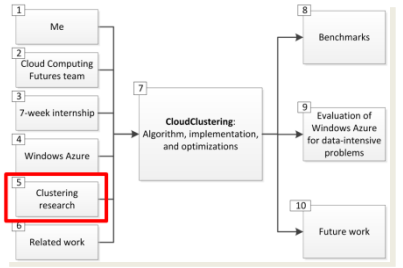
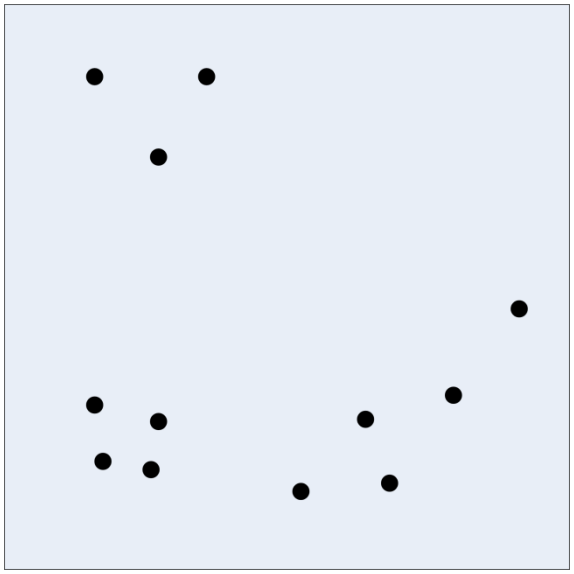
Clustering



k-means



$k = 3$

- Minimizes the *within-cluster sum of squares*:

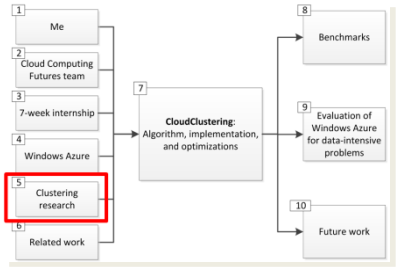
$$\sum_{i=1}^{k} \sum_{p \in C_i} \|p - \mu_i\|^2$$

For each cluster

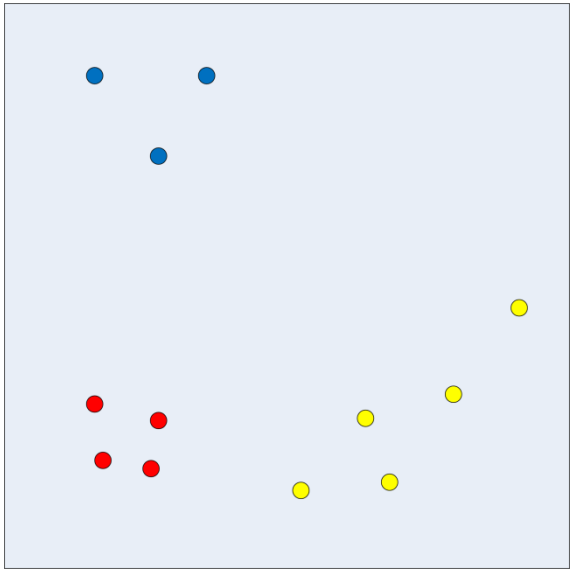
For each point in the cluster

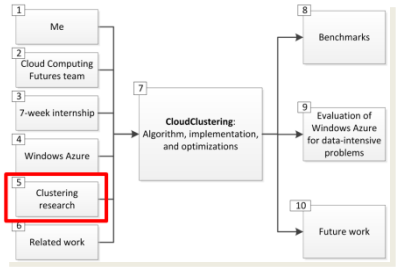
Distance from point to centroid

Clustering



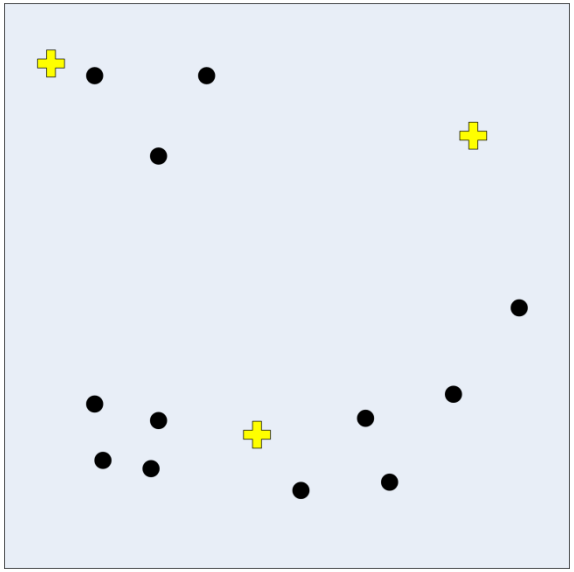
Target clustering





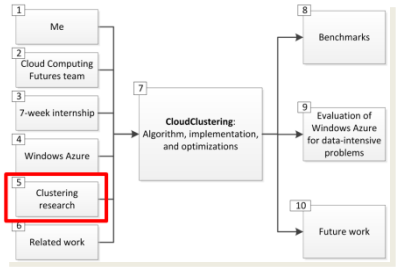
Clustering

1. Initialization

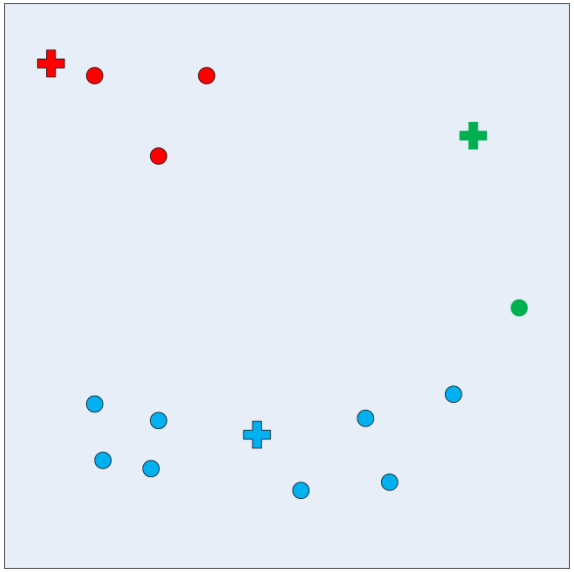


$k = 3$

Clustering



2. Assign Points to Centroids #1



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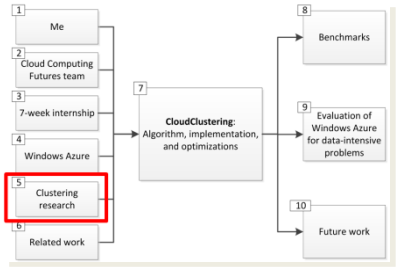
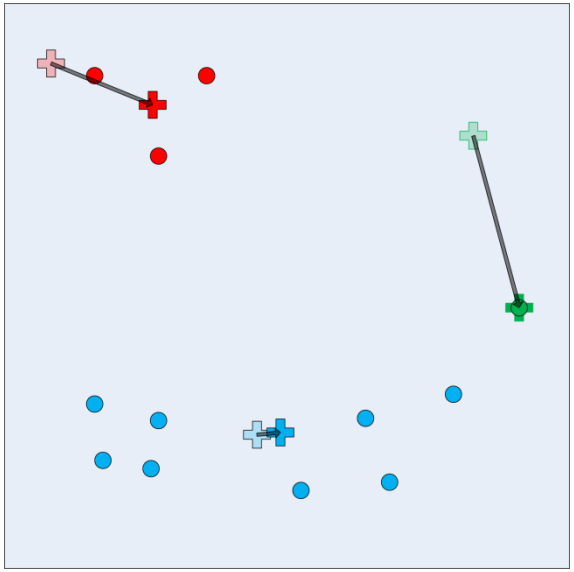


3. Recalculate Centroids #1



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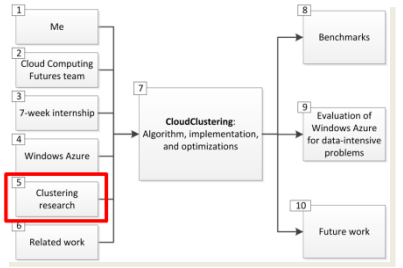
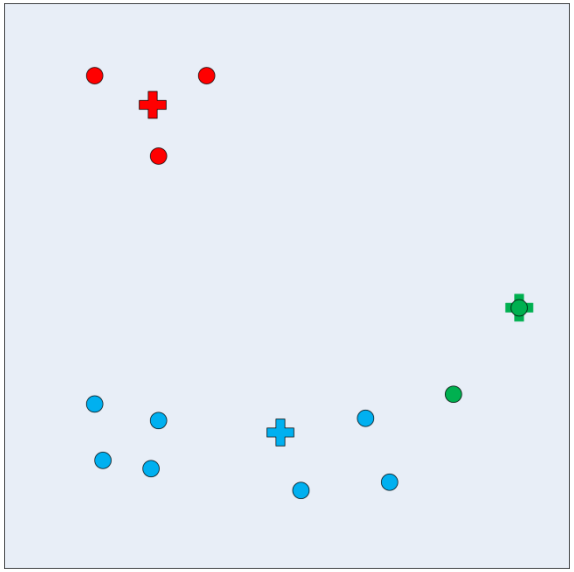
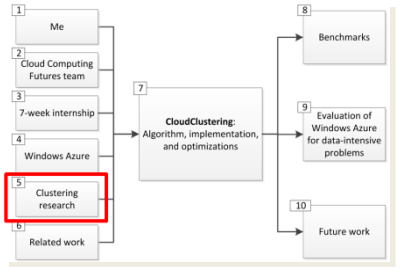


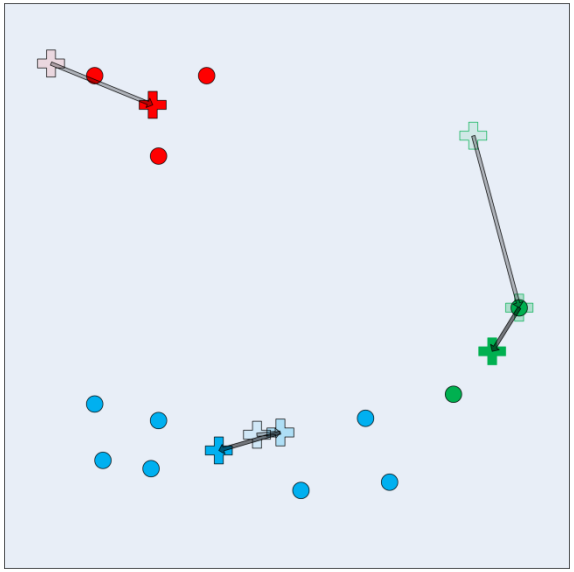
4. Assign Points to Centroids #2



Clustering



5. Recalculate Centroids #2



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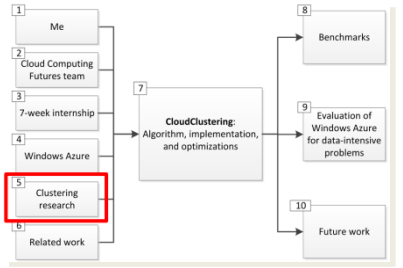
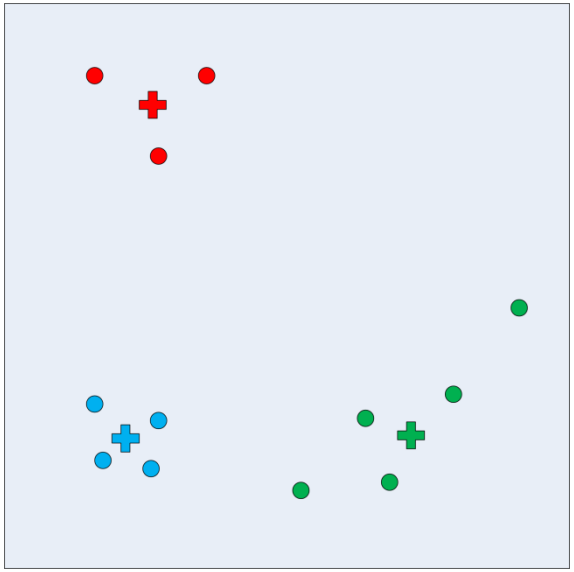


Stopping Condition



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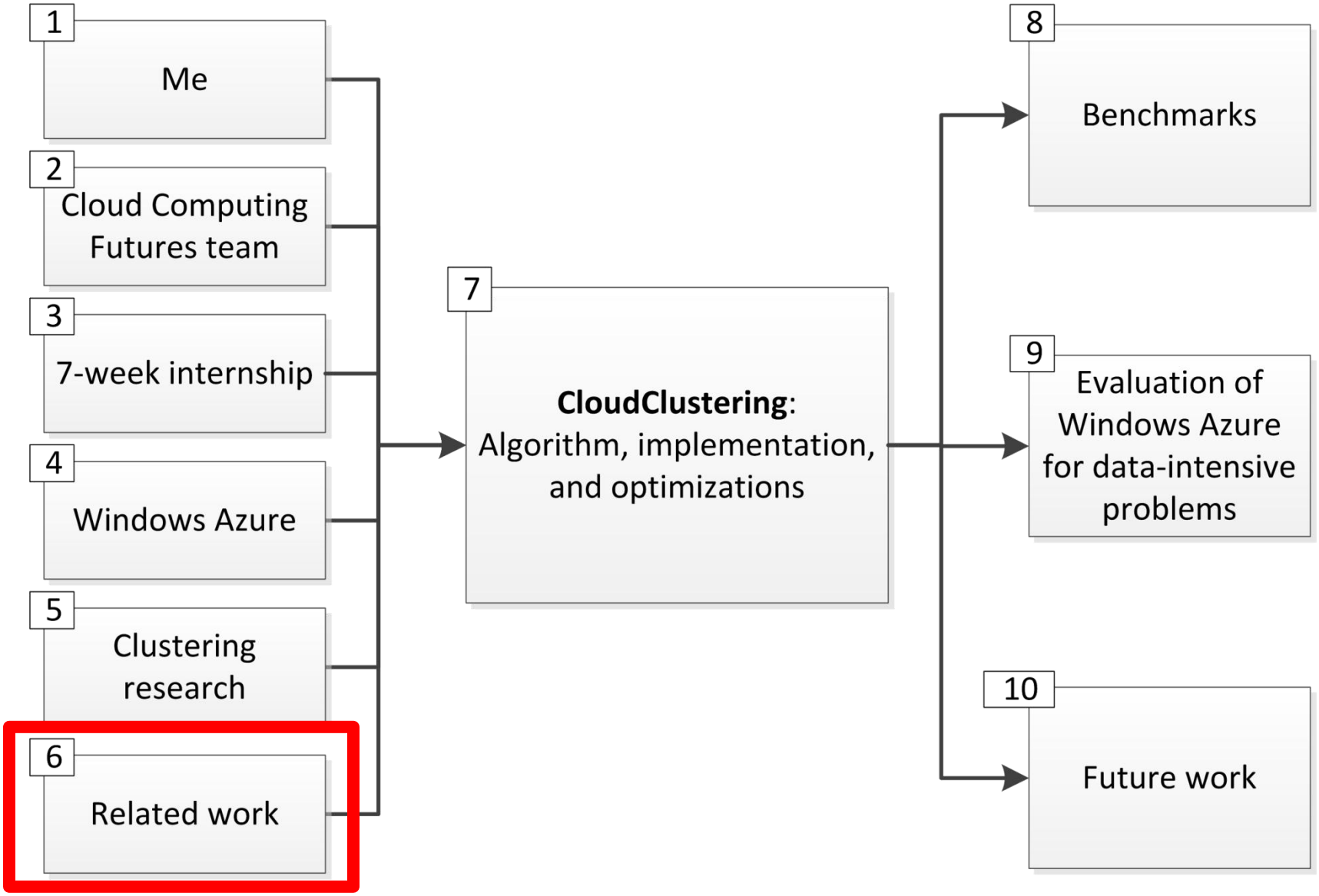
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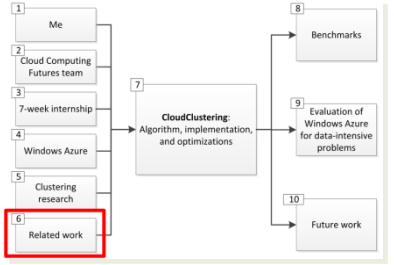
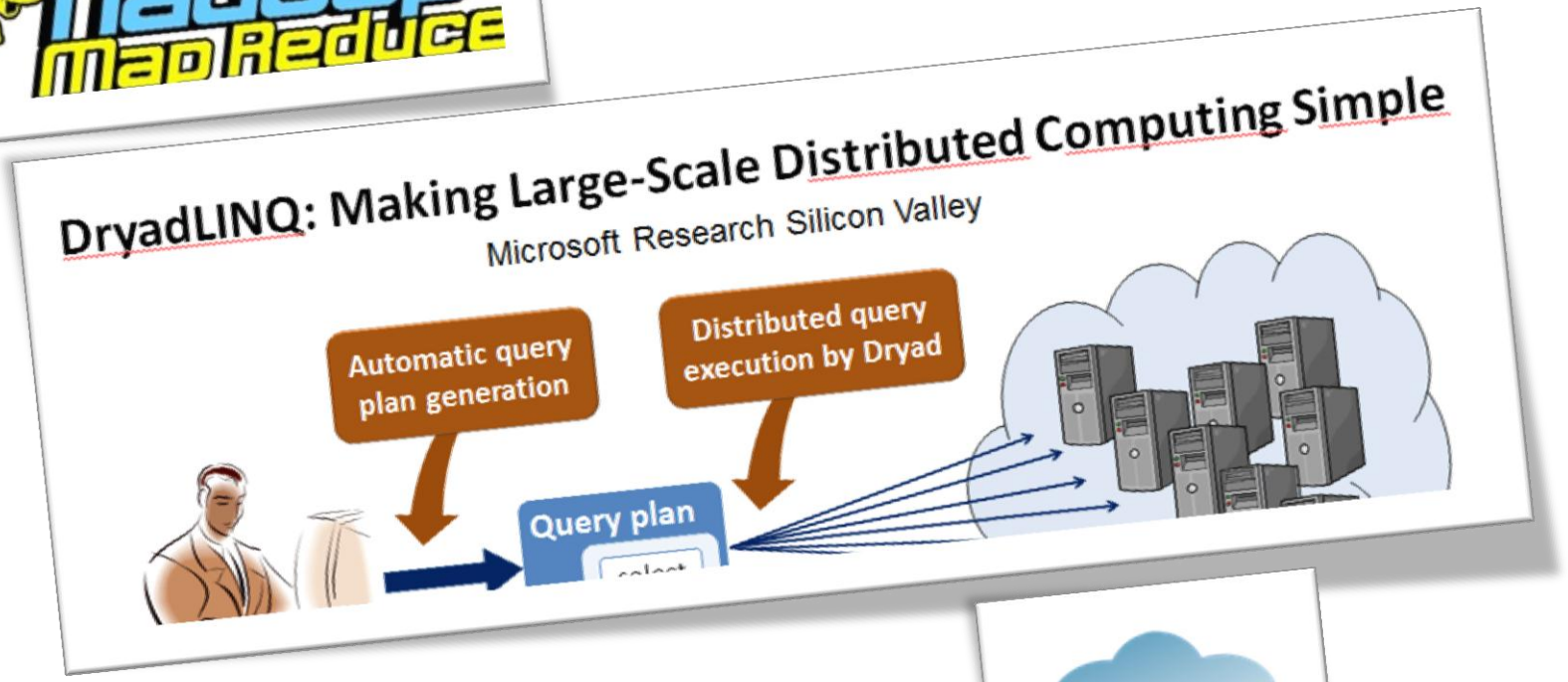
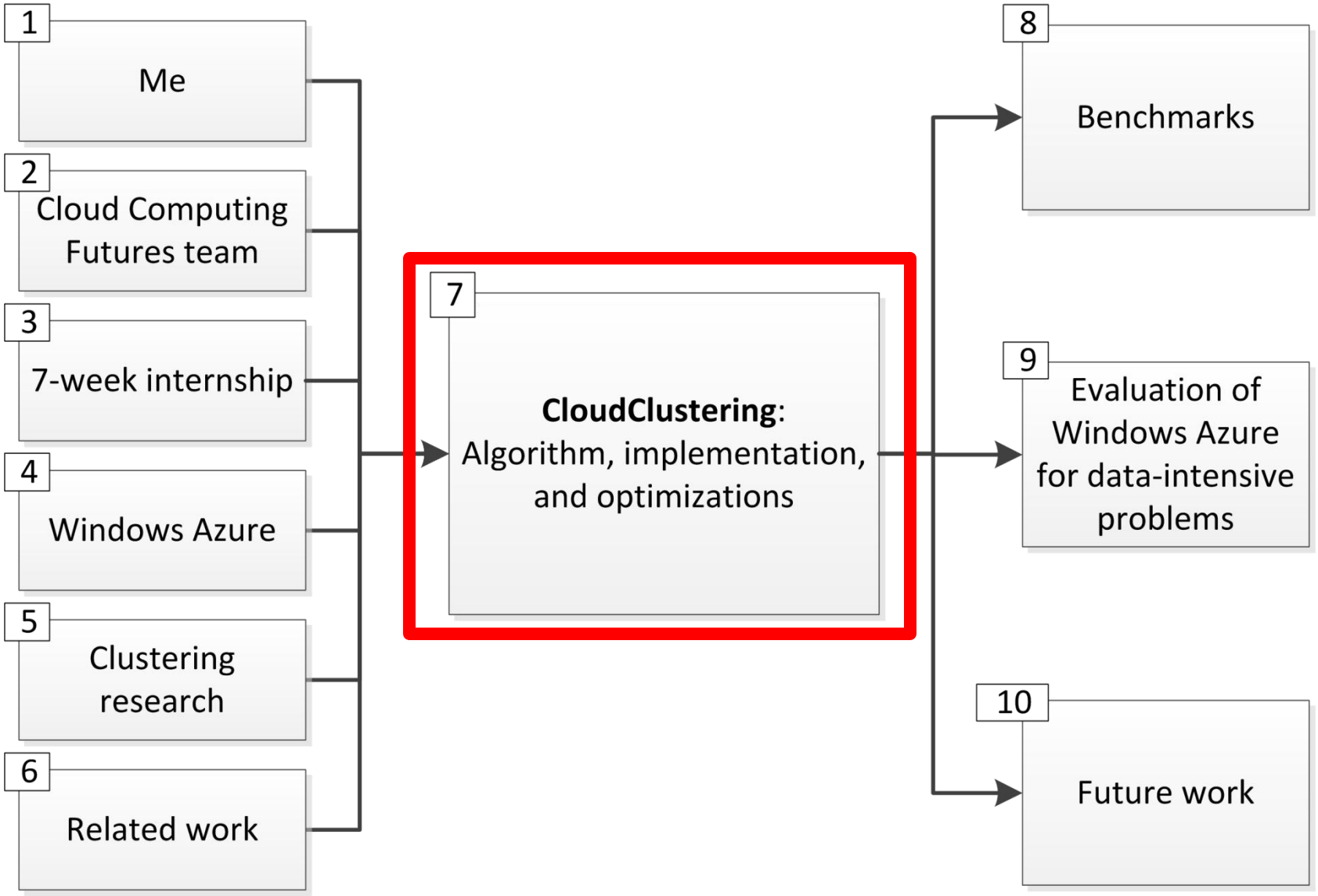
Future work

Related Work

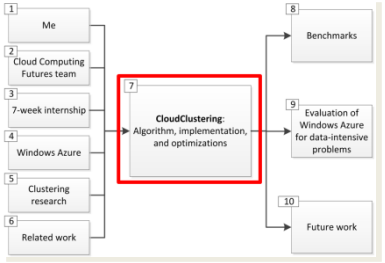




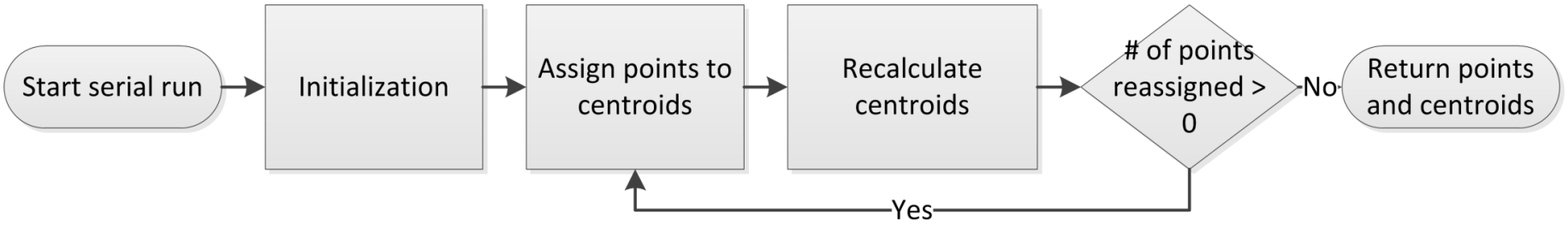
Agenda


1
Me
2
Cloud Computing Futures team
3
7-week internship
4
Windows Azure
5
Clustering research
6
Related work
7
CloudClustering: Algorithm, implementation, and optimizations
8
Benchmarks
9
Evaluation of Windows Azure for data-intensive problems
10
Future work

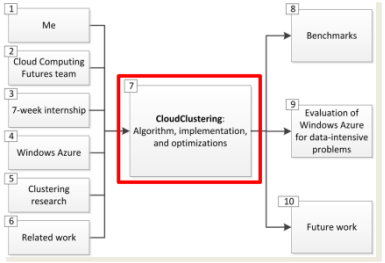
CloudClustering: Algorithm



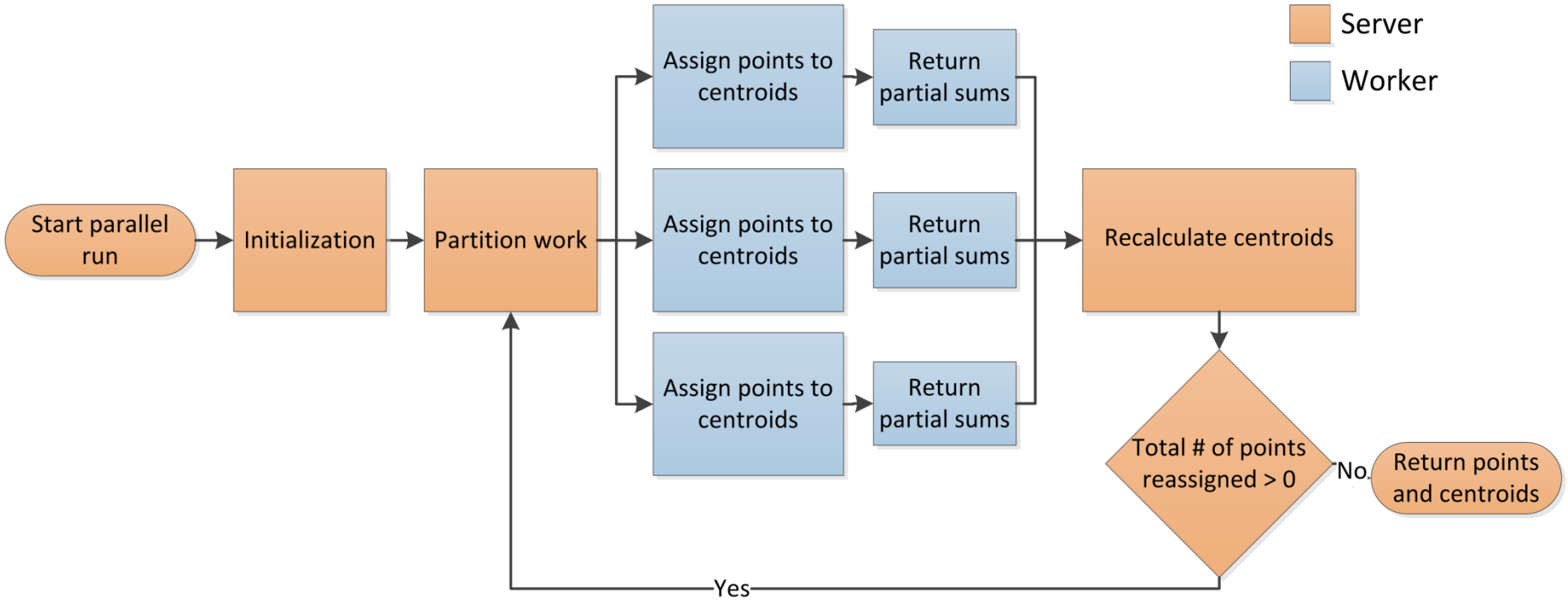
Conventional (Serial) k-means



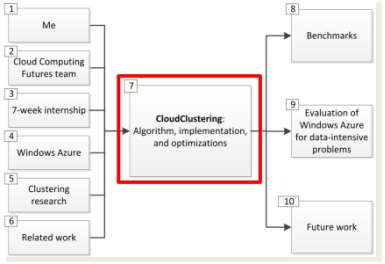
CloudClustering: Algorithm

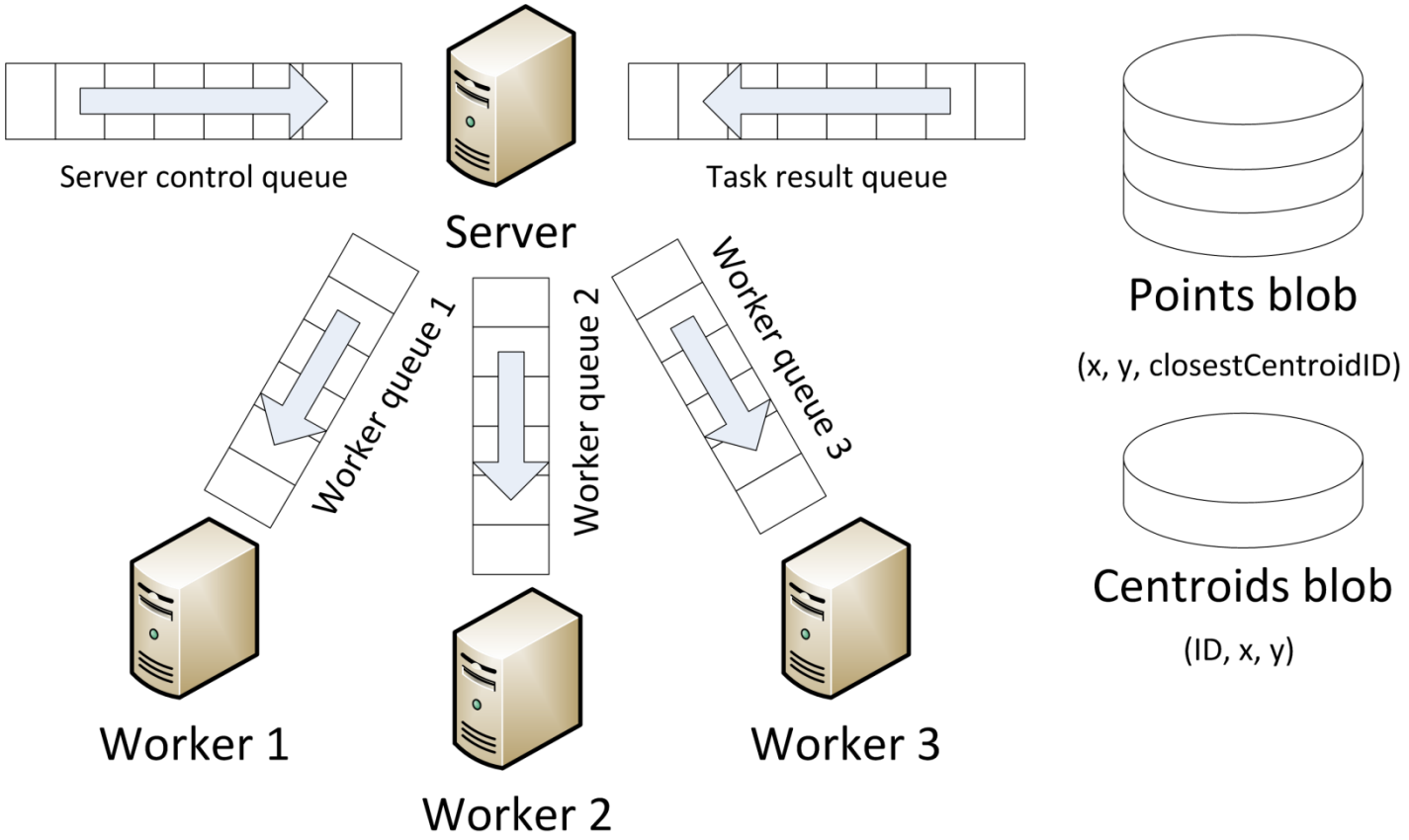


Parallel k-means

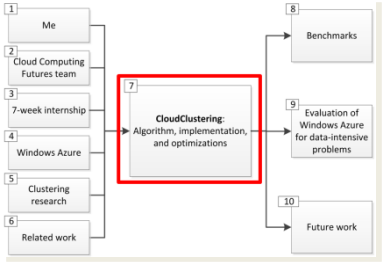


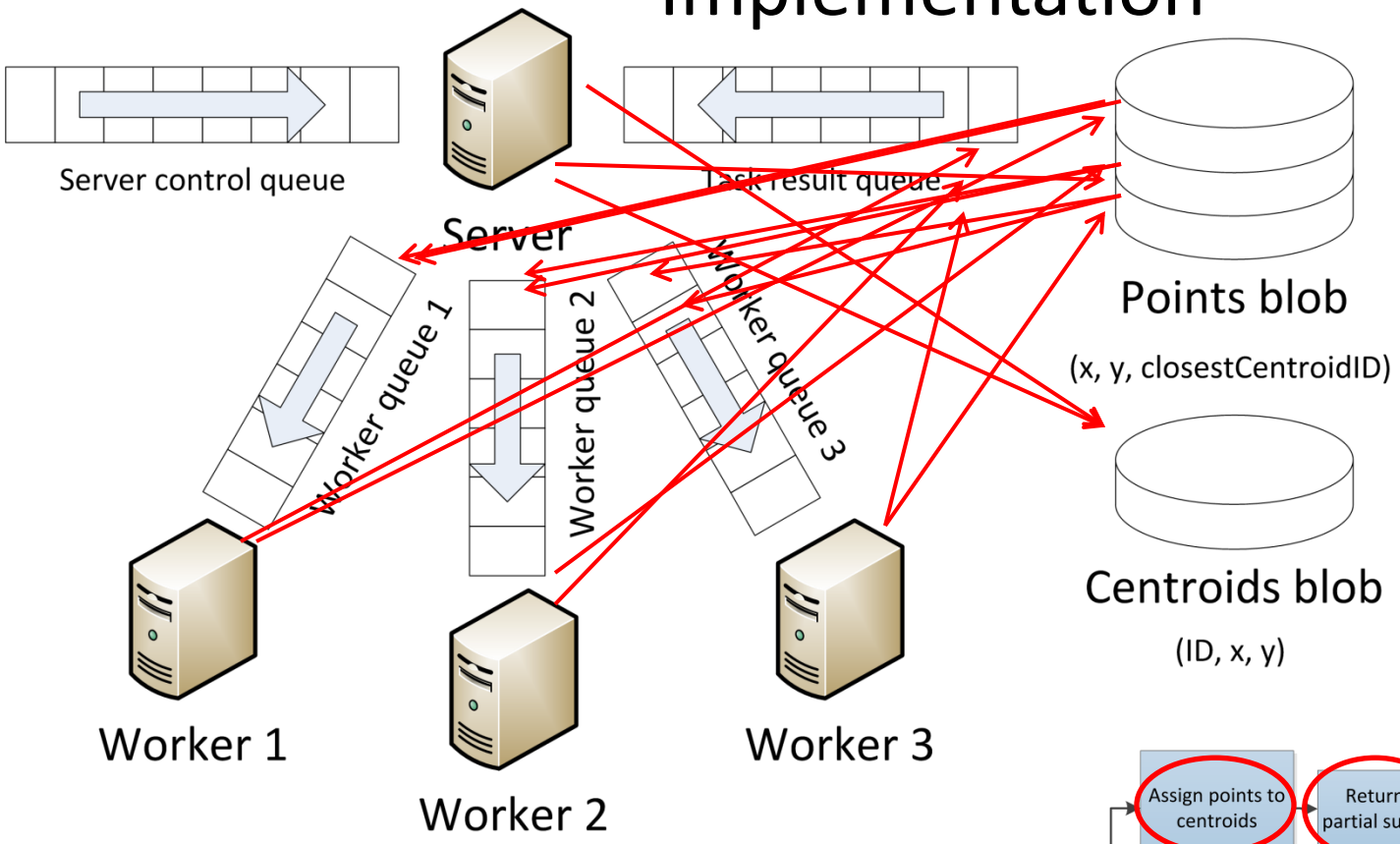
CloudClustering: Implementation

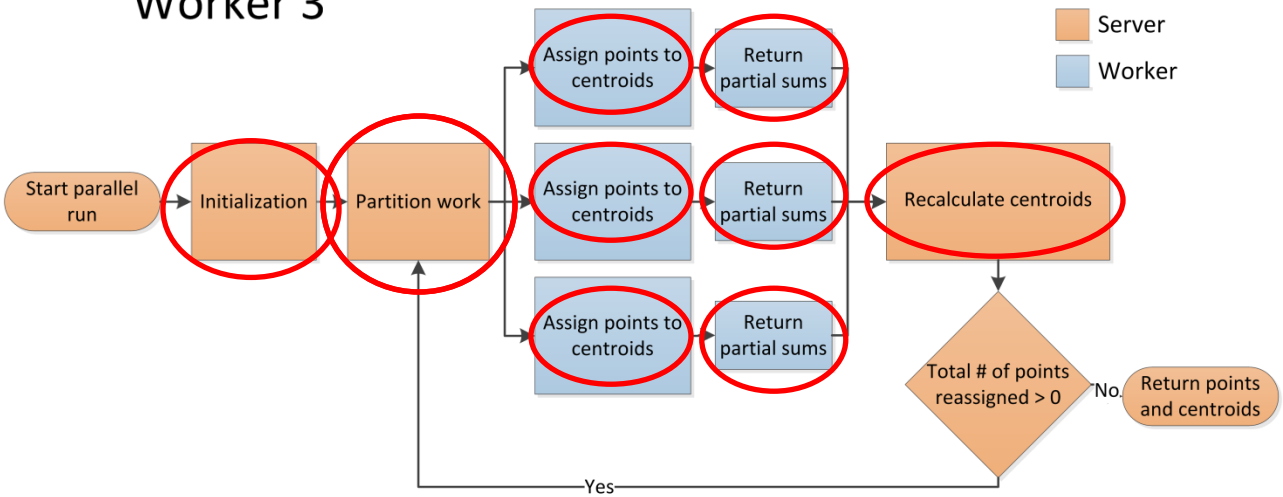




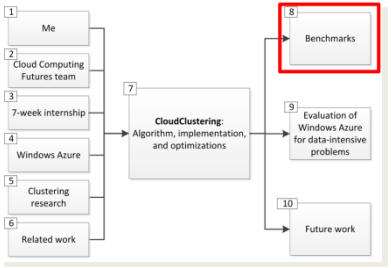
CloudClustering: Implementation





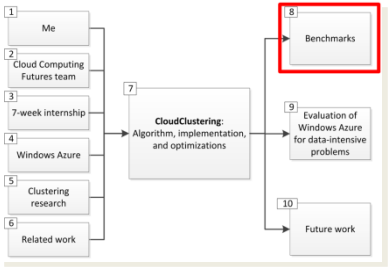


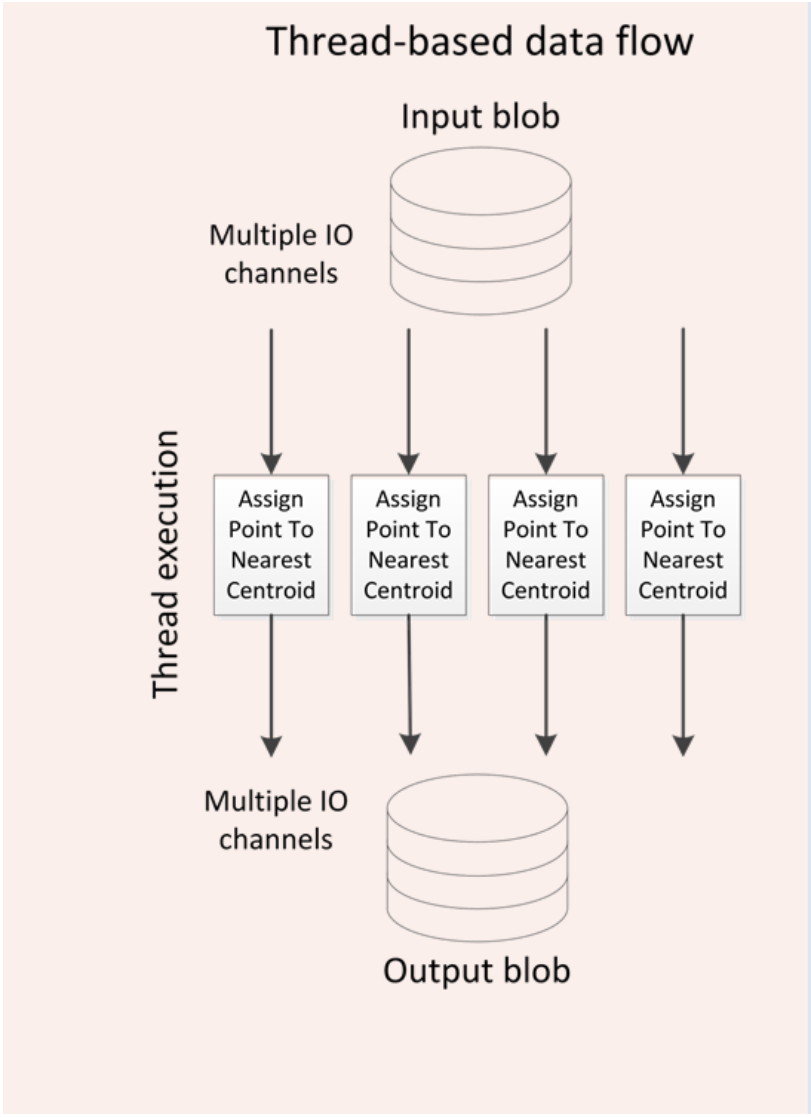
CloudClustering: Leveraging the cloud

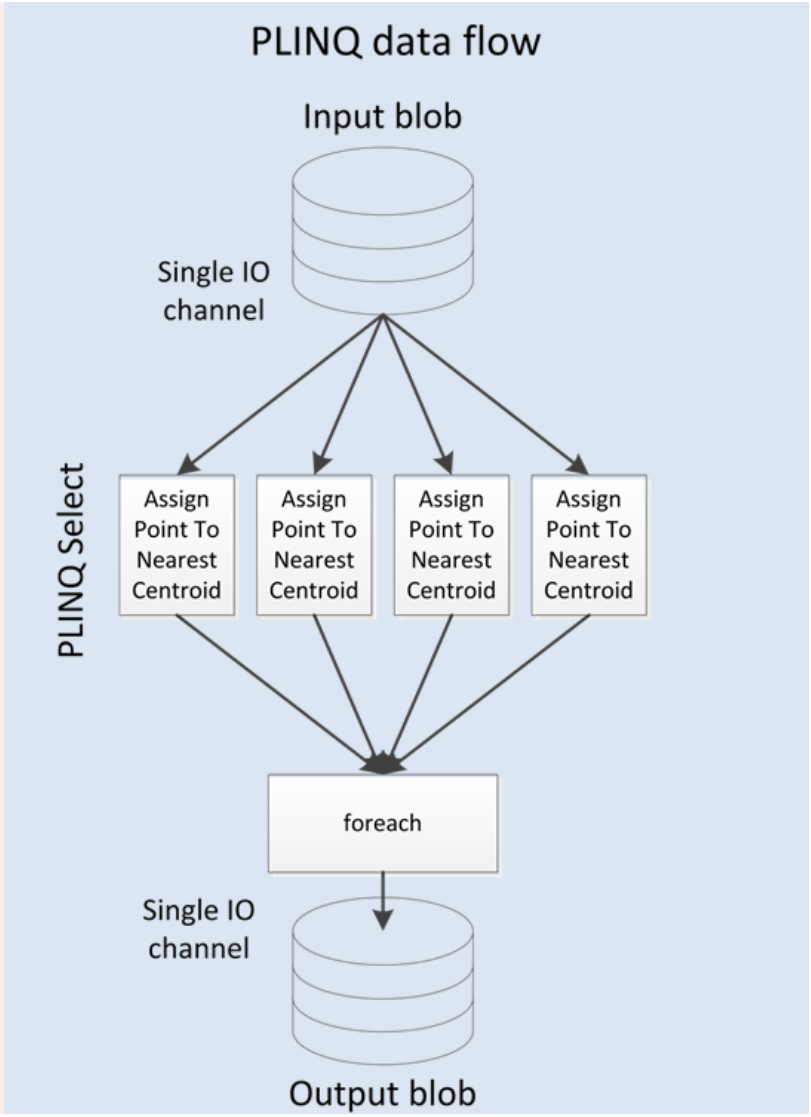


- **Multicore Parallelism**
- **Data Affinity**
- **Efficient Blob Concatenation**
- **Dynamic Scalability**

CloudClustering: Multicore Parallelism







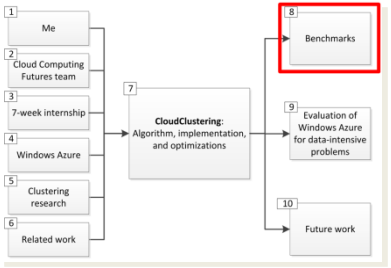
Thread-based

```
private void ProcessPoints()
{
    CloudBlockBlob pointsBlob = AzureHelper.GetBlob(task.Points);
    // Do the mapping and write the new blob
    int numThreads = Environment.ProcessorCount;
    PointsProcessedData[,] pointSumsPerCentroidPerThread = new PointsProcessedData[numThreads, task.K];
    int[] pointsChangedPerThread = new int[numThreads];
    string[][] blockIDsPerThread = new string[numThreads][];
    System.Threading.Tasks.Parallel.For(0, numThreads, threadID =>
    {
        using (ObjectCachedStreamReader<ClusterPoint> stream = new ObjectCachedStreamReader<ClusterPoint>(pointsBlob,
ClusterPoint.FromByteArray, ClusterPoint.Size, AzureHelper.GetLocalResourceRootPath("cache"), task.JobID.ToString(),
task.PartitionNumber, task.M, subPartitionNumber: threadID, subTotalPartitions: numThreads))
        {
            // Process the points
            ObjectBlockWriter<ClusterPoint> writeStream = new ObjectBlockWriter<ClusterPoint>(pointsBlob, point =>
point.ToByteArray(), ClusterPoint.Size);
            foreach (var point in stream)
            {
                // Assign the point to the nearest centroid
                Guid oldCentroidID = point.CentroidID;
                int closestCentroidIndex = centroids.MinIndex(centroid => Point.Distance(point, centroid));
                Guid newCentroidID = point.CentroidID = centroids[closestCentroidIndex].ID;
                // Write the updated point to the writeStream
                writeStream.Write(point);
                // Update the number of points changed
                if (oldCentroidID != newCentroidID)
                {
                    pointsChangedPerThread[threadID]++;
                }
                // Update the point sums
                if (pointSumsPerCentroidPerThread[threadID, closestCentroidIndex] == null)
                {
                    pointSumsPerCentroidPerThread[threadID, closestCentroidIndex] = new PointsProcessedData();
                }
                pointSumsPerCentroidPerThread[threadID, closestCentroidIndex].PartialPointSum += point;
                pointSumsPerCentroidPerThread[threadID, closestCentroidIndex].NumPointsProcessed++;
            }
            // Collect the block IDs from writeStream
            writeStream.FlushBlock();
            blockIDsPerThread[threadID] = writeStream.BlockList.ToArray();
        }
    });
    // Combine the per-thread block lists and write the full block list to a blob. Then include that as part of TaskResult
    List<string> blockIDs = new List<string>();
    foreach (string[] blockIDsFromThread in blockIDsPerThread)
    {
        blockIDs.AddRange(blockIDsFromThread);
    }
    CloudBlob blockIDsBlob = AzureHelper.CreateBlob(task.JobID.ToString(), Guid.NewGuid().ToString());
    using (Stream stream = blockIDsBlob.OpenWrite())
    {
        BinaryFormatter bf = new BinaryFormatter();
        bf.Serialize(stream, blockIDs);
    }
    TaskResult.PointsBlockListBlob =  blockIDsBlob.Uri;
    // Total up the per-thread pointSumsPerCentroid
    TaskResult.PointsProcessedDataByCentroid = new Dictionary<Guid, PointsProcessedData>();
    for (int i = 0; i < task.K; ++i)
    {
        Guid centroidID = centroids[i].ID;
        TaskResult.PointsProcessedDataByCentroid[centroidID] = new PointsProcessedData();
        for (int j = 0; j < numThreads; ++j)
        {
            if (pointSumsPerCentroidPerThread[j, i] != null)
            {
                TaskResult.PointsProcessedDataByCentroid[centroidID].PartialPointSum += pointSumsPerCentroidPerThread[j,
i].PartialPointSum;
                TaskResult.PointsProcessedDataByCentroid[centroidID].NumPointsProcessed += pointSumsPerCentroidPerThread[j,
i].NumPointsProcessed;
            }
        }
    }
    // Total up the per-thread numPointsChanged
    TaskResult.NumPointsChanged = 0;
    foreach (int threadPointsChanged in pointsChangedPerThread)
    {
        TaskResult.NumPointsChanged += threadPointsChanged;
    }
}
```

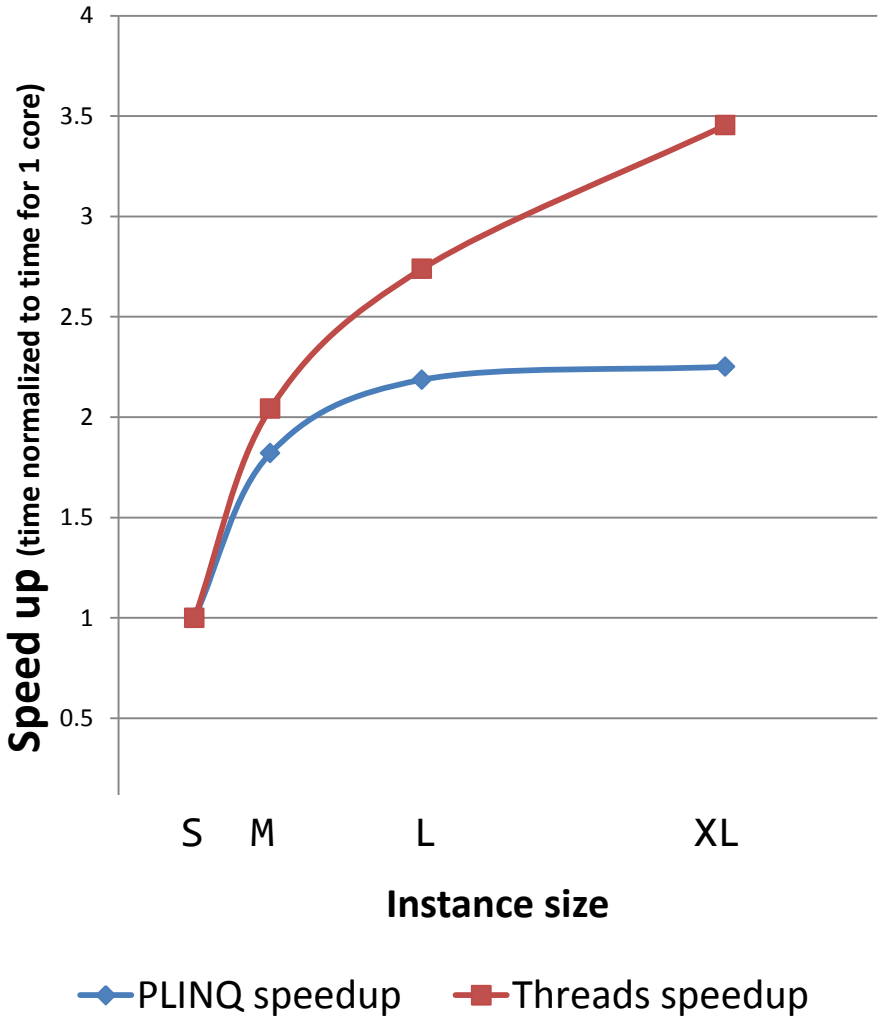
PLINQ

```
private void ProcessPoints()
{
    CloudBlockBlob pointsBlob = AzureHelper.GetBlob(task.Points);
    // Do the mapping and write the new blob
    using (ObjectStreamReader<ClusterPoint> stream = new ObjectStreamReader<ClusterPoint>(pointsBlob,
ClusterPoint.FromByteArray, ClusterPoint.Size, task.PartitionNumber, task.M))
    {
        var assignedPoints = stream.AsParallel().Select(AssignClusterPointToNearestCentroid);
        ObjectBlockWriter<ClusterPoint> writeStream = new ObjectBlockWriter<ClusterPoint>(pointsBlob, point =>
point.ToByteArray(), ClusterPoint.Size);
        TaskResult.NumPointsChanged = 0;
        TaskResult.PointsProcessedDataByCentroid = new Dictionary<Guid, PointsProcessedData>();
        // Pipelined execution -- see http://msdn.microsoft.com/en-us/magazine/cc163329.aspx
        foreach (var result in assignedPoints)
        {
            // Write the point to the new blob
            writeStream.Write(result.Point);
            // Update the number of points changed counter
            if (result.PointWasChanged)
            {
                TaskResult.NumPointsChanged++;
            }
            // Add to the appropriate centroid group
            if (!TaskResult.PointsProcessedDataByCentroid.ContainsKey(result.Point.CentroidID))
            {
                TaskResult.PointsProcessedDataByCentroid[result.Point.CentroidID] = new PointsProcessedData();
            }
            TaskResult.PointsProcessedDataByCentroid[result.Point.CentroidID].NumPointsProcessed++;
            TaskResult.PointsProcessedDataByCentroid[result.Point.CentroidID].PartialPointSum += result.Point;
        }
        // Send the block list as part of TaskResult
        writeStream.FlushBlock();
        TaskResult.PointsBlockList = writeStream.BlockList;
    }
}
private ClusterPointProcessingResult AssignClusterPointToNearestCentroid(ClusterPoint clusterPoint)
{
    ClusterPoint result = new ClusterPoint(clusterPoint);
    result.CentroidID = centroids.MinElement(centroid => Point.Distance(clusterPoint, centroid)).ID;
    return new ClusterPointProcessingResult
    {
        Point = result,
        PointWasChanged = clusterPoint.CentroidID != result.CentroidID
    };
}
```

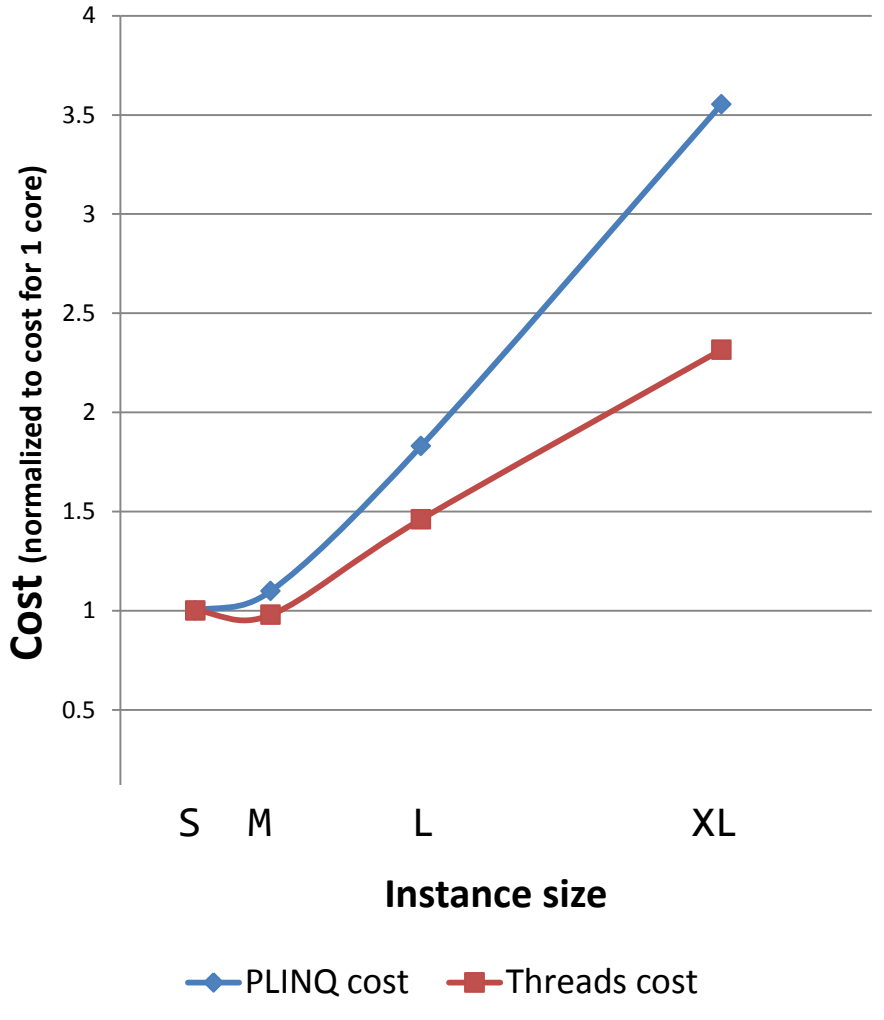
CloudClustering: Multicore Parallelism

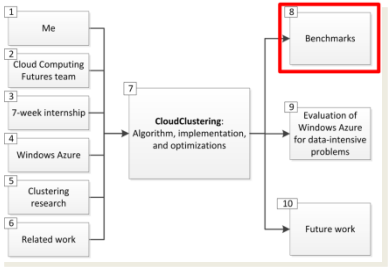


Scale-up: Speed up for varying instance size, PLINQ vs. Threads

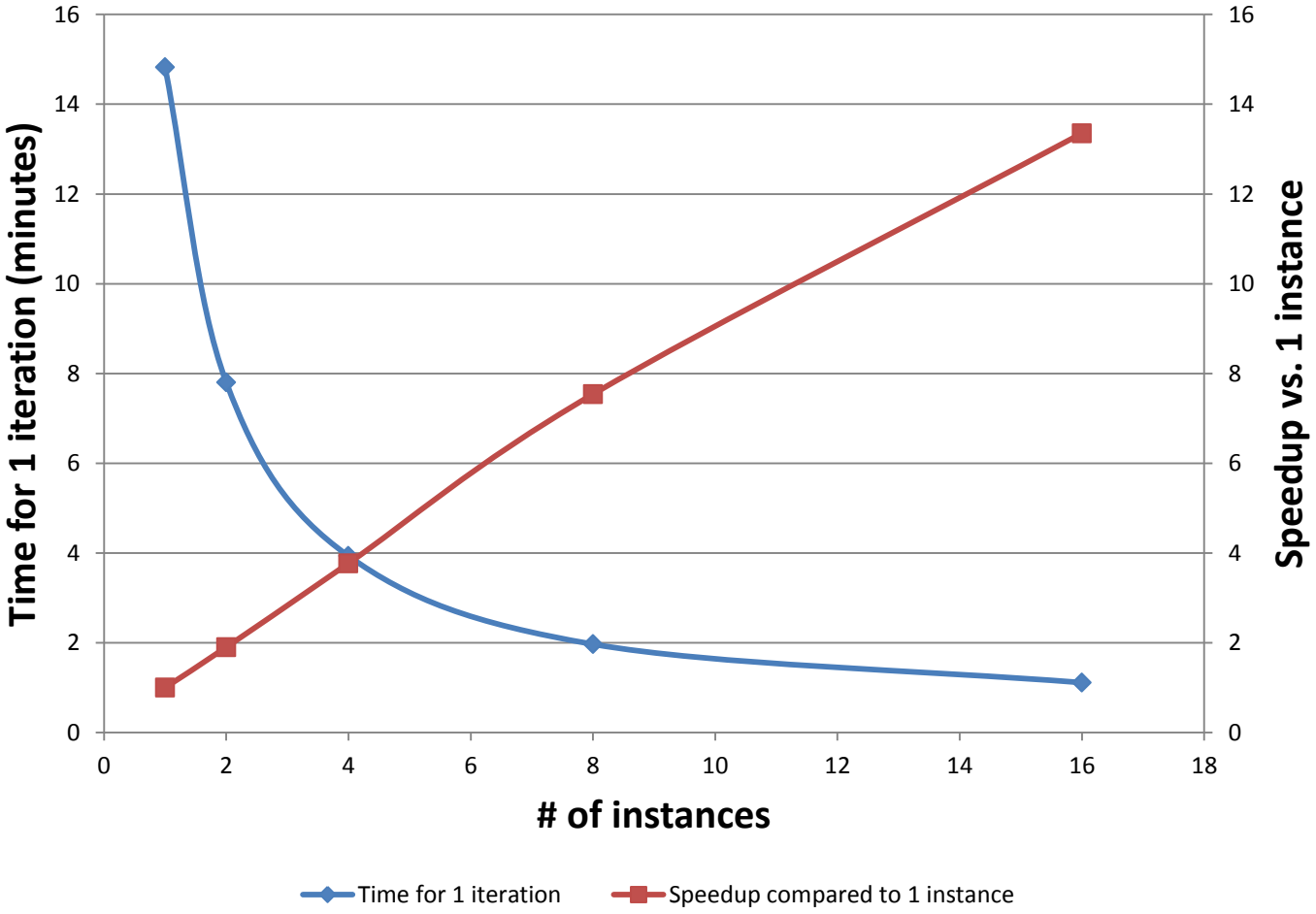


Scale-up: Cost for varying instance size, PLINQ vs. Threads

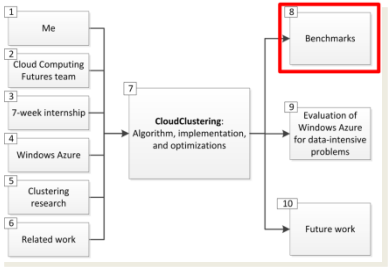


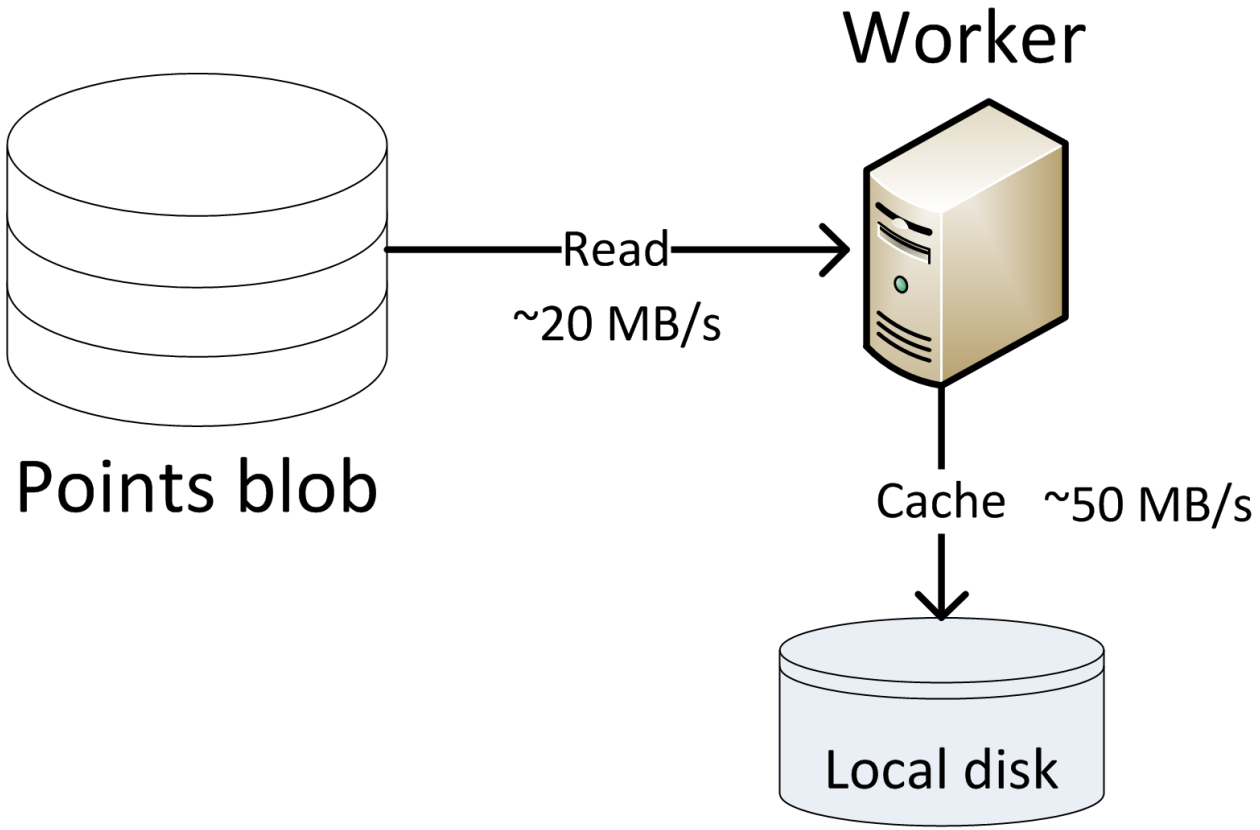


Scale-out: Time and speedup for varying instance counts

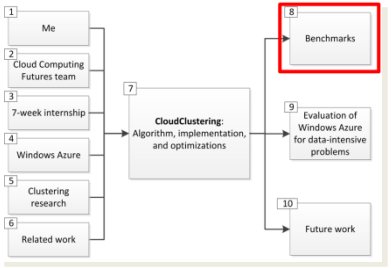


CloudClustering: Data Affinity

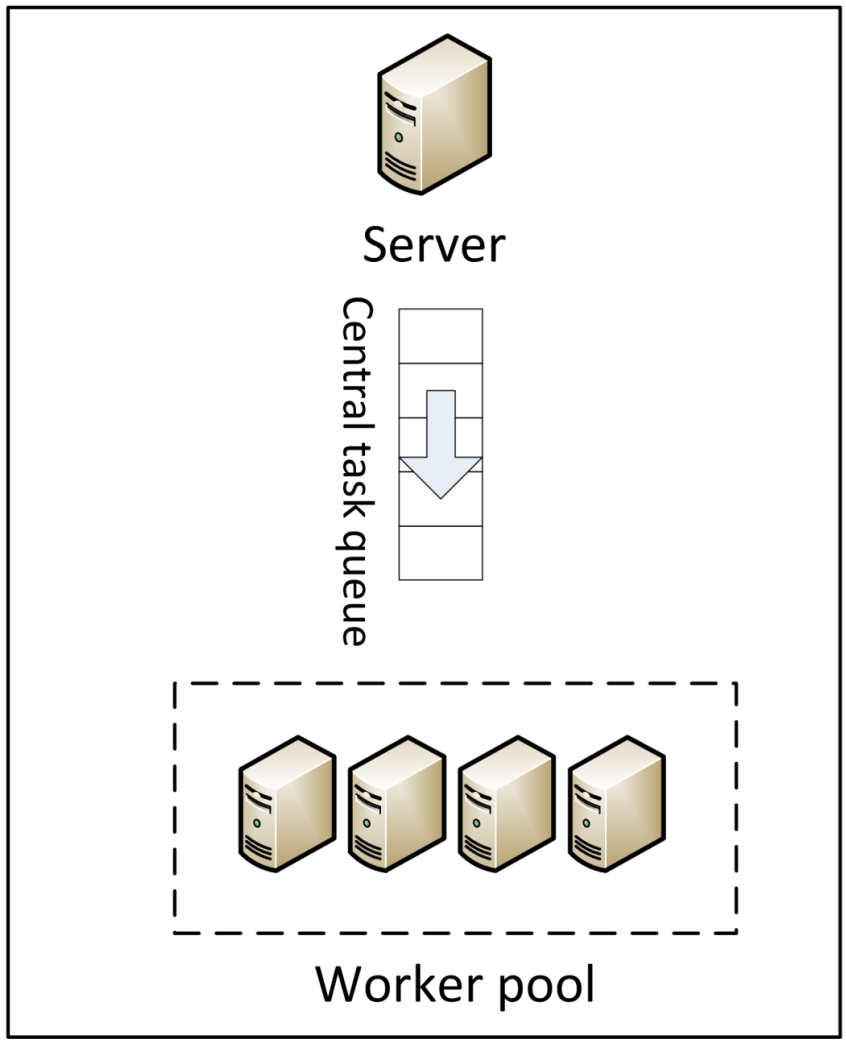




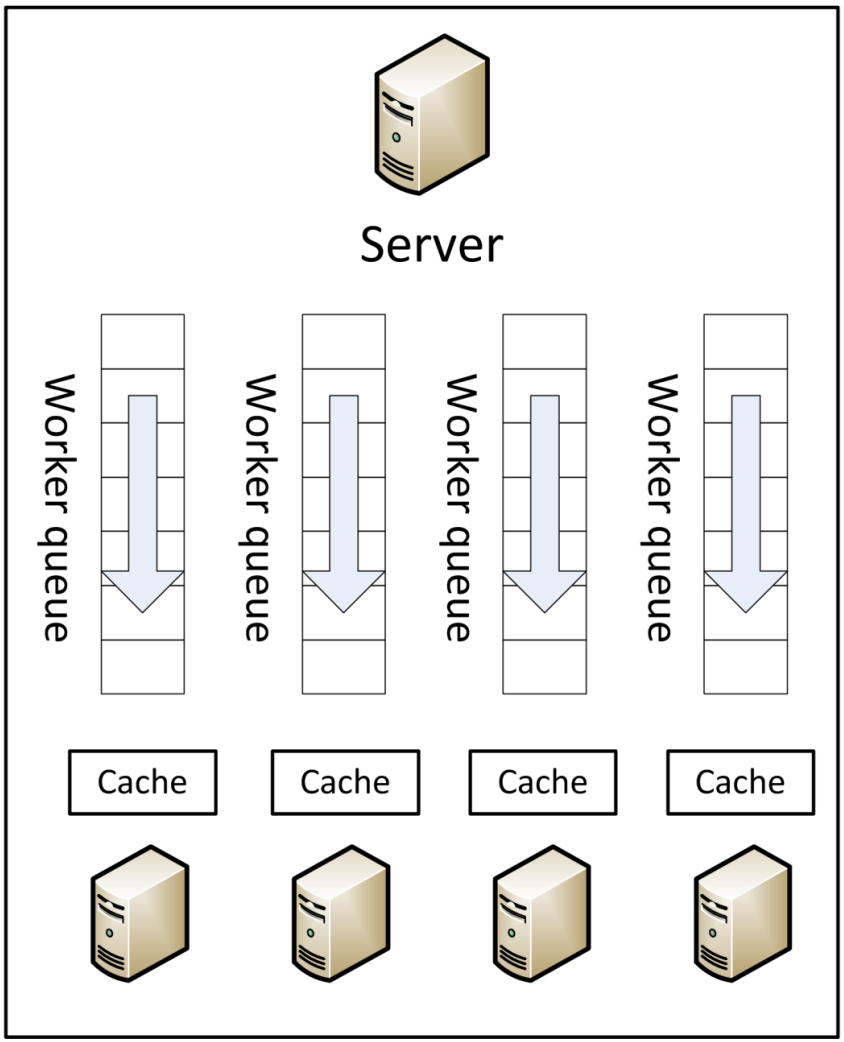
CloudClustering: Data Affinity



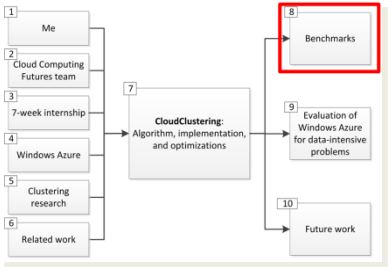
Typical Azure architecture

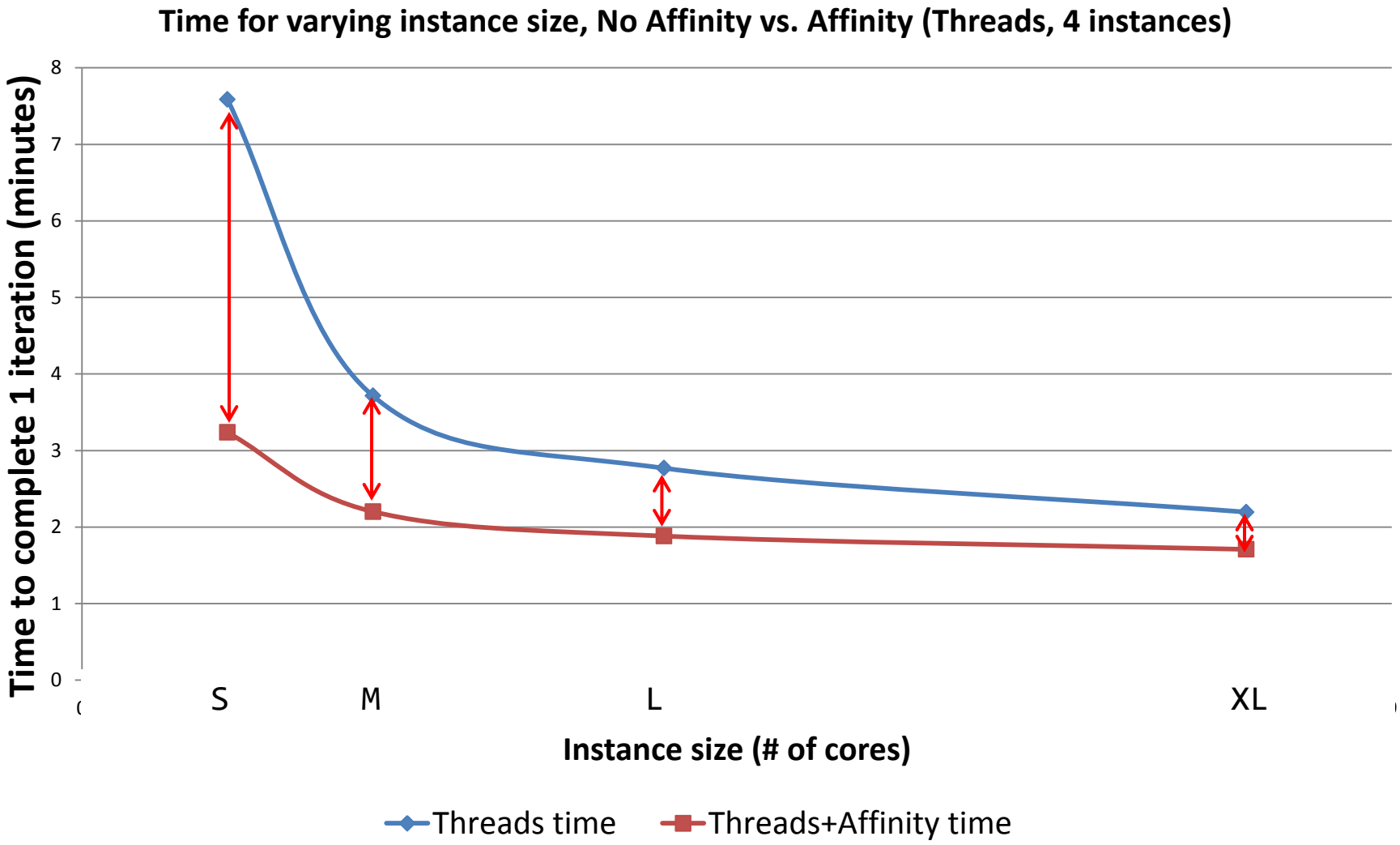


Architecture with data affinity

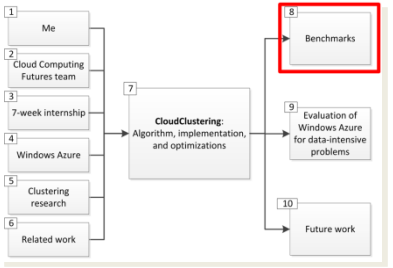


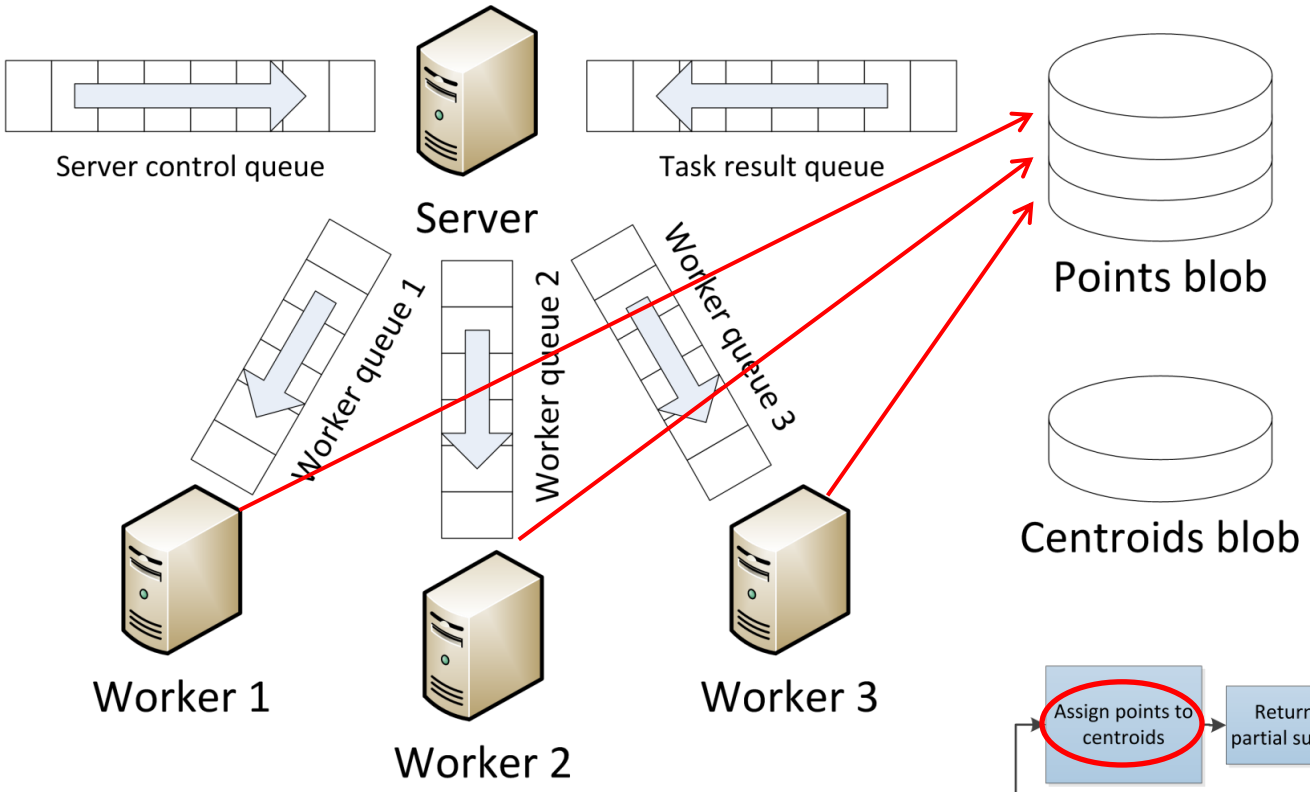
CloudClustering: Data Affinity

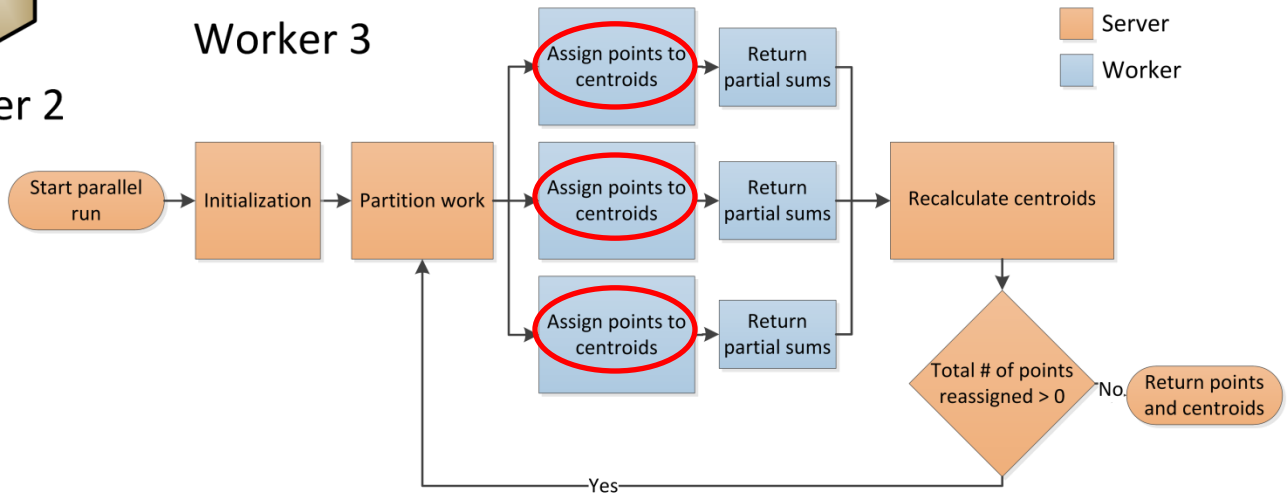




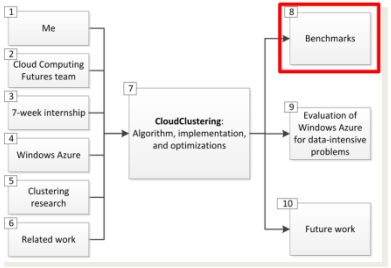
CloudClustering: Efficient Blob Concatenation

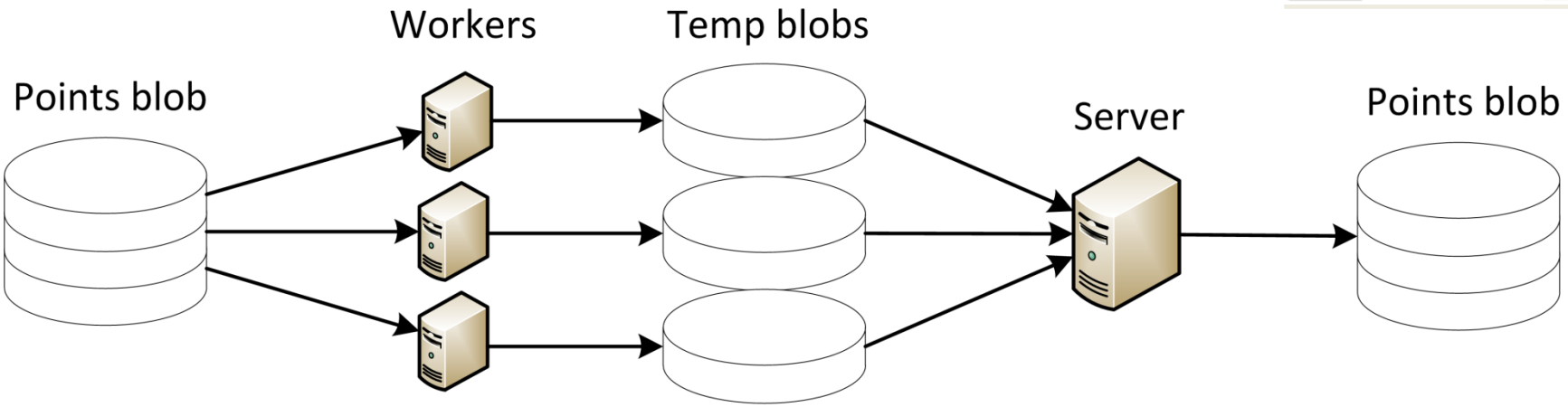


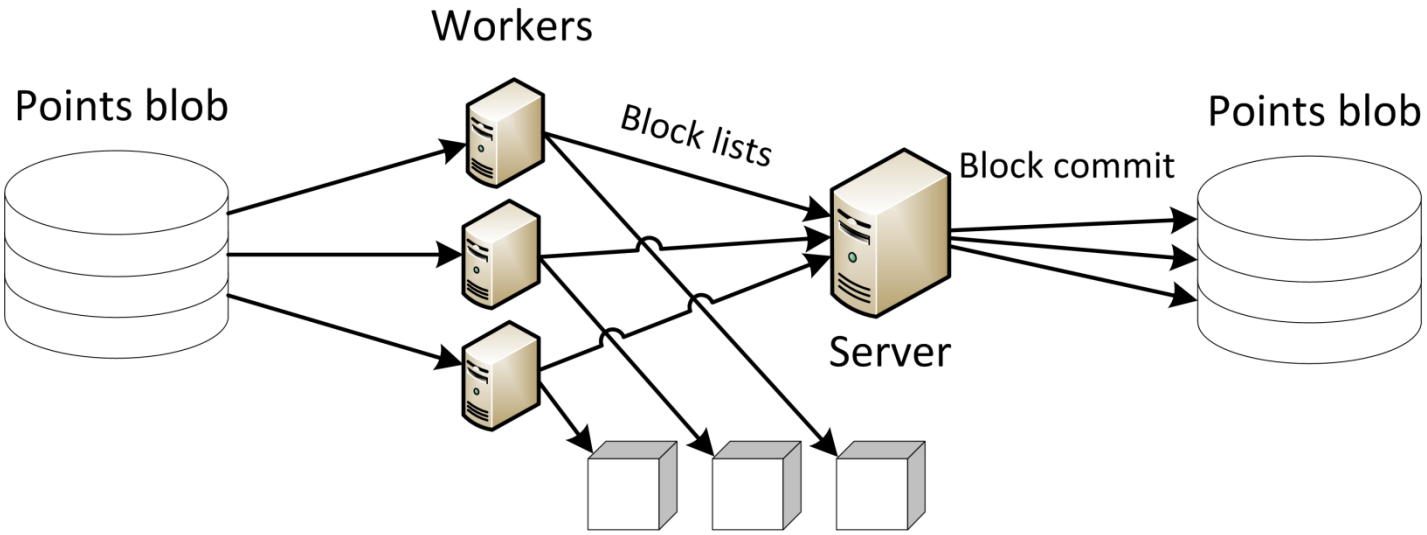




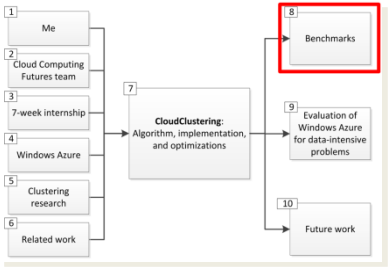
CloudClustering: Efficient Blob Concatenation

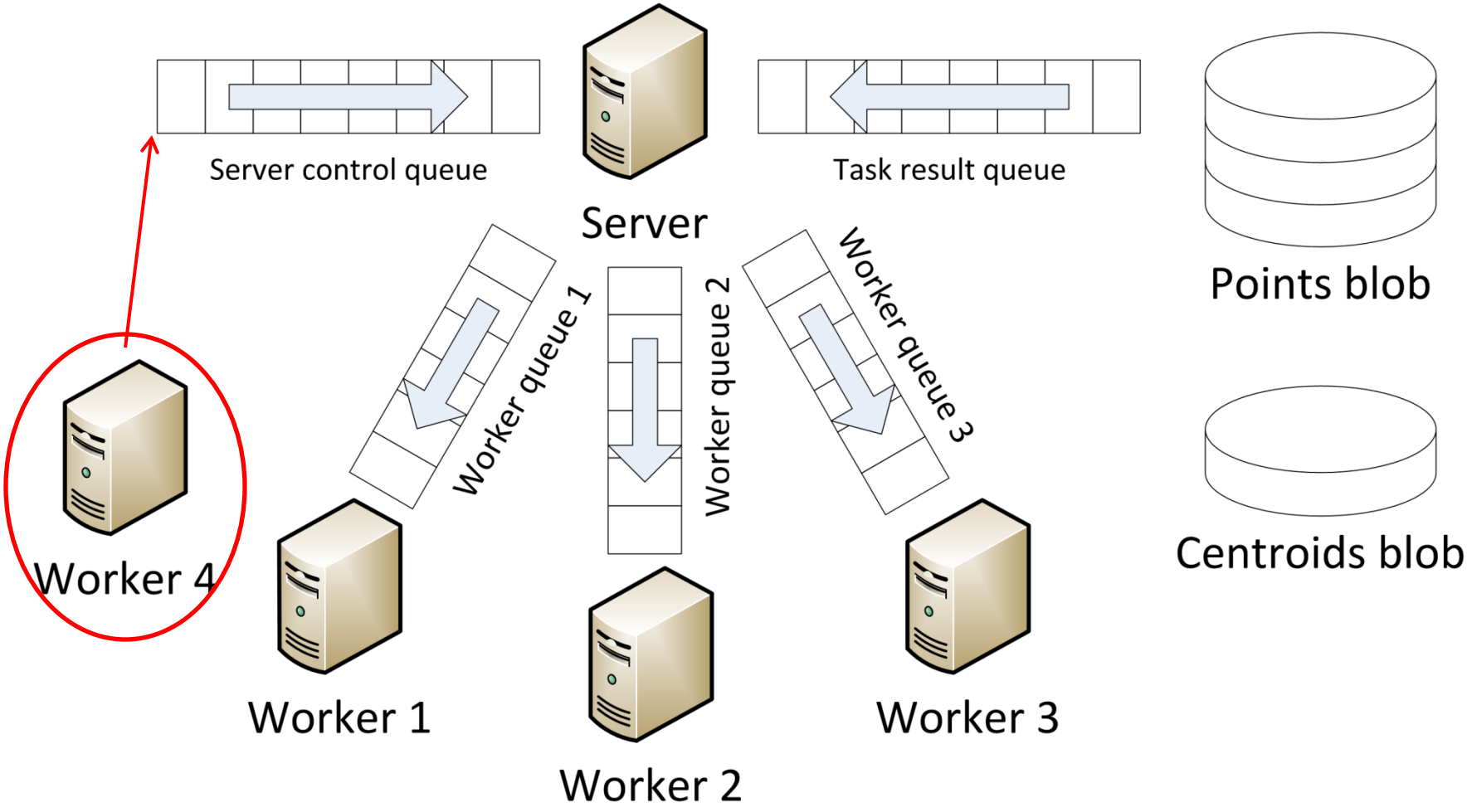




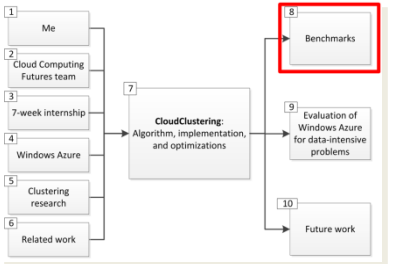


CloudClustering: Dynamic Scalability





CloudClustering: Demo



Home Page

http://cloudclustering.cloudapp.net/

CLOUD CLUSTERING

ANKUR DAVE

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JOB INPUT

Points (n): 500000

or Points File: Choose File No file chosen

or Points Blob URI:

Clusters (k): 5

Max iterations: 5 (0 is unlimited)

Notification email:

Run K-Means

Clear Blobs

Refresh

STATUS

Click Run K-Means to see results.

Download Log

POINTS BLOB

CENTROIDS BLOB

PERFORMANCE

Method Min time (s) Average time (s) Max time (s) Count

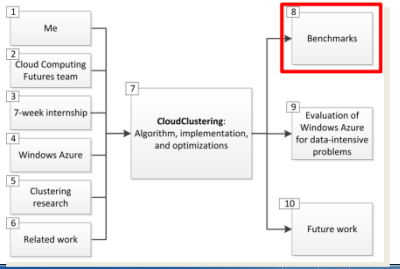
Iteration Method Time taken (s)

WORKERS

Worker ID

VISUALIZATION

CloudClustering: Demo



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Cloud Clustering

Ankur Dave

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Job Input

Points (n): 500000

or Points File: Choose File No file chosen

or Points Blob URI:

Clusters (k): 5

Max iterations: 5 (0 is unlimited)

Notification email:

Run K-Means

Clear Blobs

Refresh

Status

Done!

Download Log

Points Blob

http://cloudclusteringstore.blob.core.windows.net/27e05c29-0782-4556-b84a-e94467dfc13d/points

Centroids Blob

http://cloudclusteringstore.blob.core.windows.net/27e05c29-0782-4556-b84a-e94467dfc13d/centroids

Performance

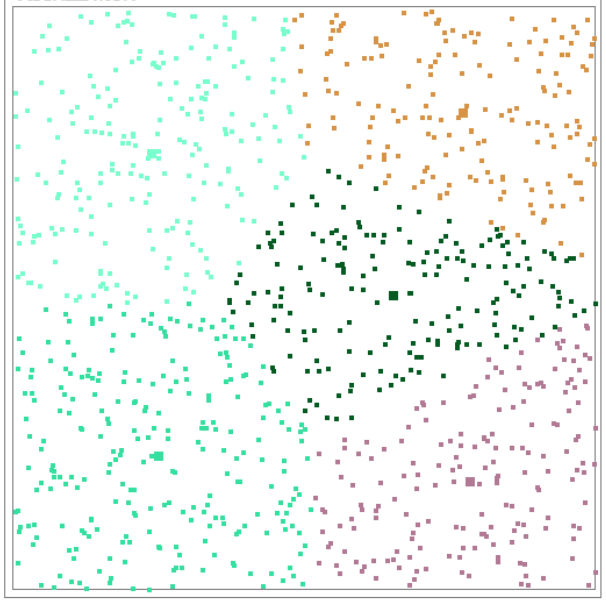
Method	Min time (s)	Average time (s)	Max time (s)	Count
InitializeStorage	6.2030853	6.2030853	6.2030853	1
EnqueueTasks	0.5624964	0.6874956	1.0781181	5
ProcessNewTask	2.5156411	4.23124963	9.5625612	20
ProcessWorkerResponse	0.1874988	0.246092175	0.4218723	20
RecalculateCentroids	0.7187454	0.75937014	0.8281197	5

Iteration	Method	Time taken (s)
0	InitializeStorage	6.2030853
0	EnqueueTasks	0.624996
0	ProcessNewTask	9.5625612
0	ProcessNewTask	9.4531511
0	ProcessNewTask	9.2968155
0	ProcessNewTask	8.90625
0	ProcessWorkerResponse	0.4218723
0	ProcessWorkerResponse	0.2343735
0	ProcessWorkerResponse	0.2187486
0	ProcessWorkerResponse	0.1874988
1	RecalculateCentroids	0.8281197
1	EnqueueTasks	0.6093711
1	ProcessNewTask	2.7500176
1	ProcessNewTask	3.0937302
1	ProcessNewTask	2.625
1	ProcessNewTask	2.5156411
1	ProcessWorkerResponse	0.2968731
1	ProcessWorkerResponse	0.3281229
1	ProcessWorkerResponse	0.2812482
1	ProcessWorkerResponse	0.2343735

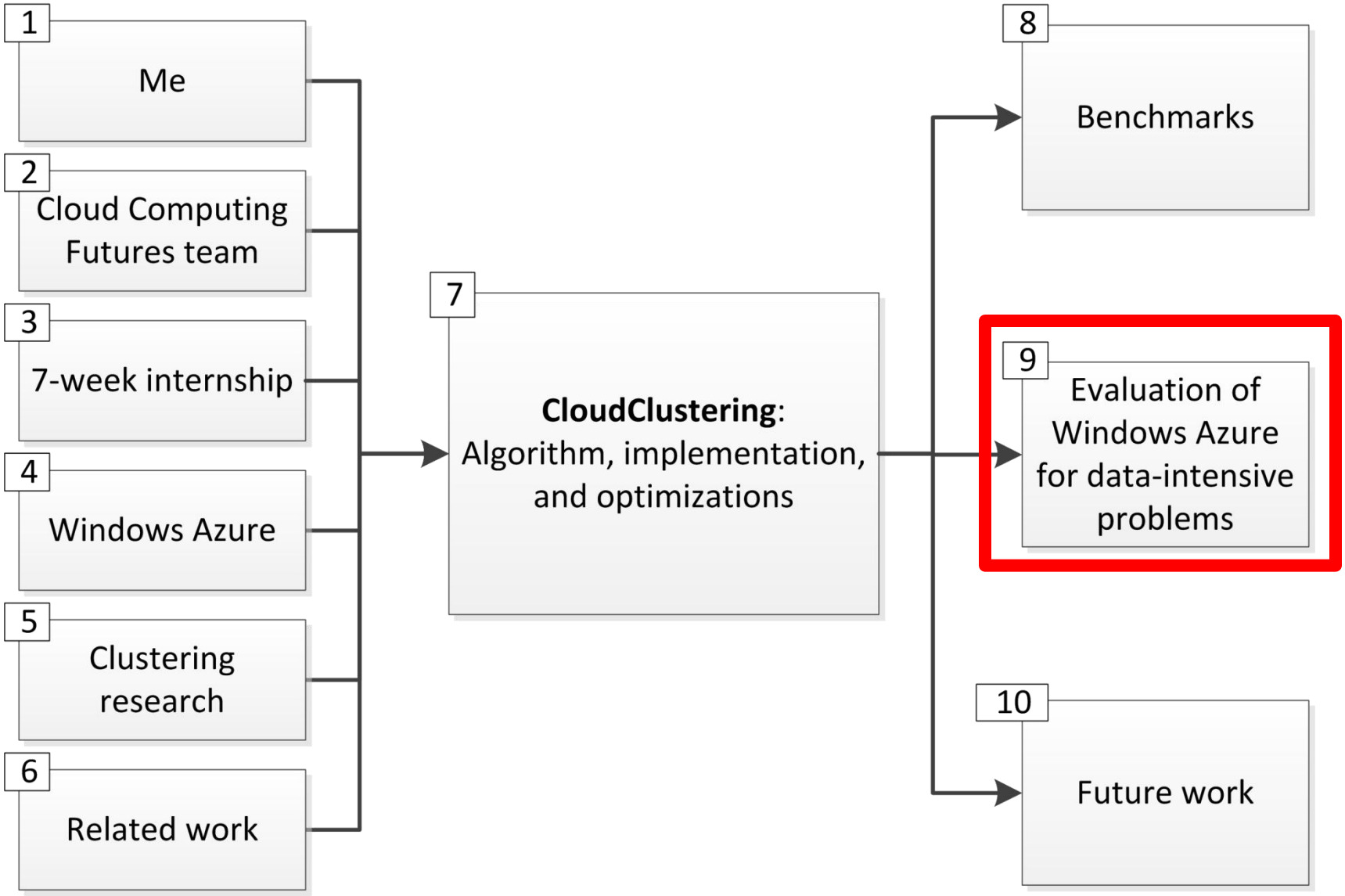
Workers

Worker ID
074b74bd-2954-4170-96f7-71676578cfdc
791dbb9b-73cc-4464-bea4-f473e1881760
c90eeba9-89a2-4db9-b751-fbe7139b8e65
fda65ade-6968-47f2-9ed6-bc66330bfa93

Visualization



Agenda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Cloud Computing Futures team
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Evaluation of Windows Azure for data-intensive problems
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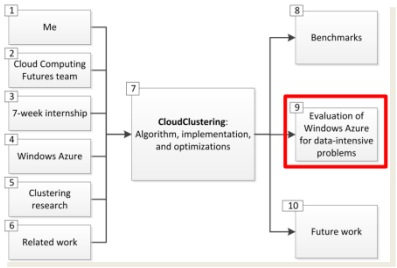
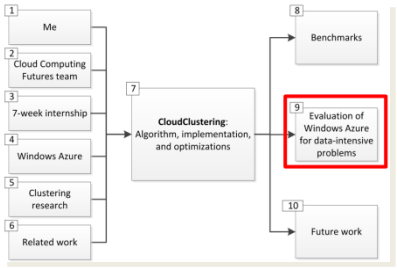
Future work

Windows Azure: Benefits



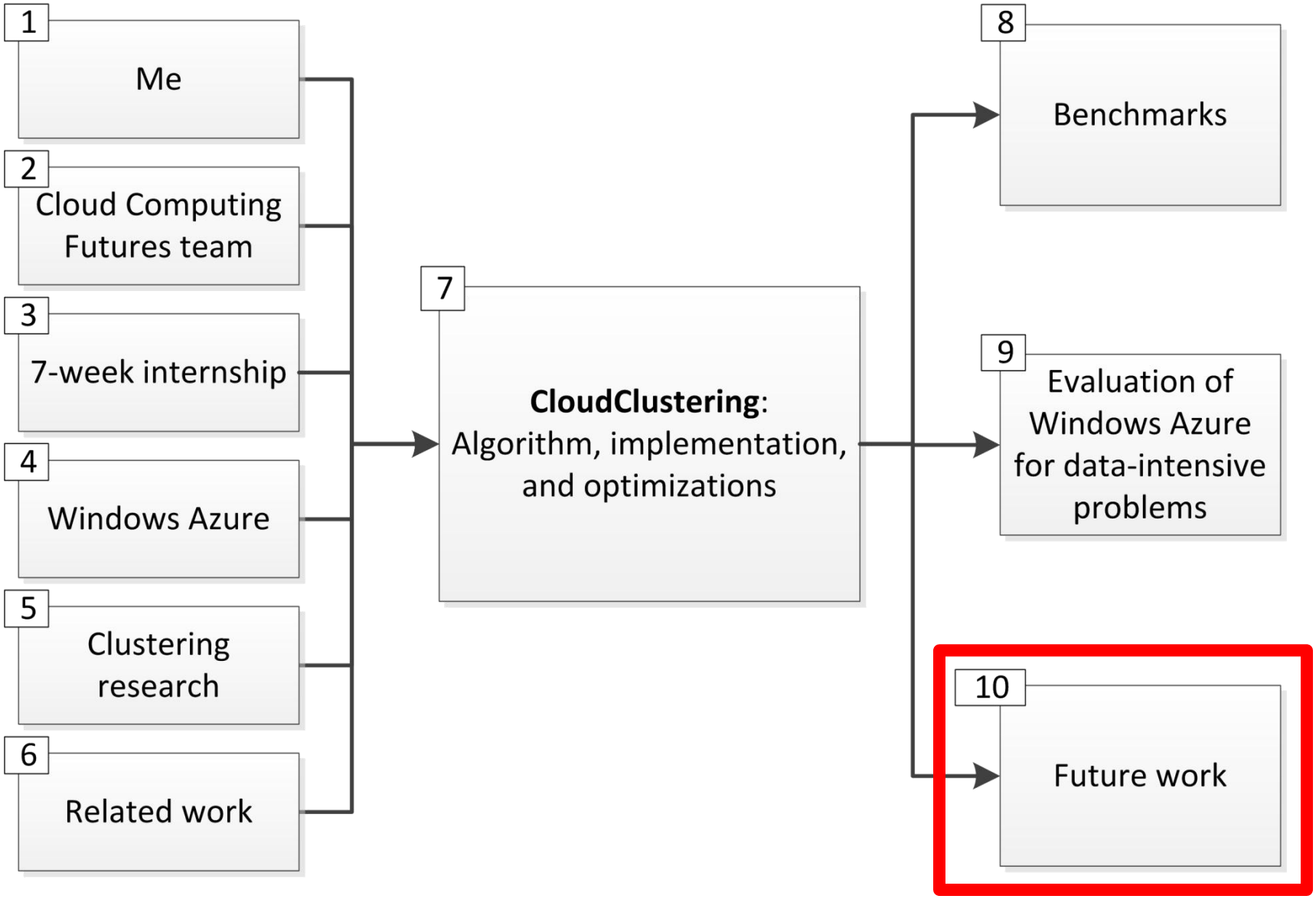
Azure is an **appropriate level of abstraction** for data-intensive algorithms like k-means.

Windows Azure: Potential Problem Areas



- On the cloud, **cost** scales directly with **usage**
  - Sub-linear speedups are not good enough!
- For data-intensive algorithms, **data affinity** gives great performance… but there's a **tradeoff**
  - Dynamic scaling is more complex
  - Fault-tolerance is even harder
- Performance test to find configuration **sweet spots**

Agenda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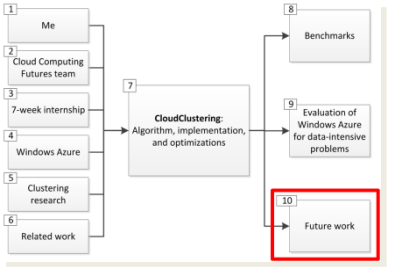

- A **compromise between worker pools and data affinity** that retains scalability and fault-tolerance
  - Buddy system
- Improved **caching** using blocks
- Fundamental improvements to the ***k*-means algorithm**
  - More efficient stopping condition
  - "Lazy" processing that eliminates synchronization barriers
- Further optimizations to **multicore parallelism**

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