Approximate Join Processing Over Data Streams

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Data Stream and Join Operator

- Data Stream Processing Systems vs. Traditional DBMS
- Sliding Window Join
  - Join the set of tuples in a bounded-size window of the most recent items in two streams

    $r(i)$ and $s(i)$, $t-w<i\leqslant t$
- Resource Limitations
  - Fast CPU vs. Slow CPU (high arriving rate)
  - Memory Restriction (Q: what's the minimum memory requirement for exact join?)

Semantic Load Shedding

- Resource Limitations – how to solve it?
  - Drop some tuples to get approximation!
- Random Load Shedding vs. Semantic Load Shedding
  - Random Load Shedding – Easy to see
  - Approximate the output of an operator by maximizing a user-defined similarity measure between the exact and the approximation

Join Processing Models

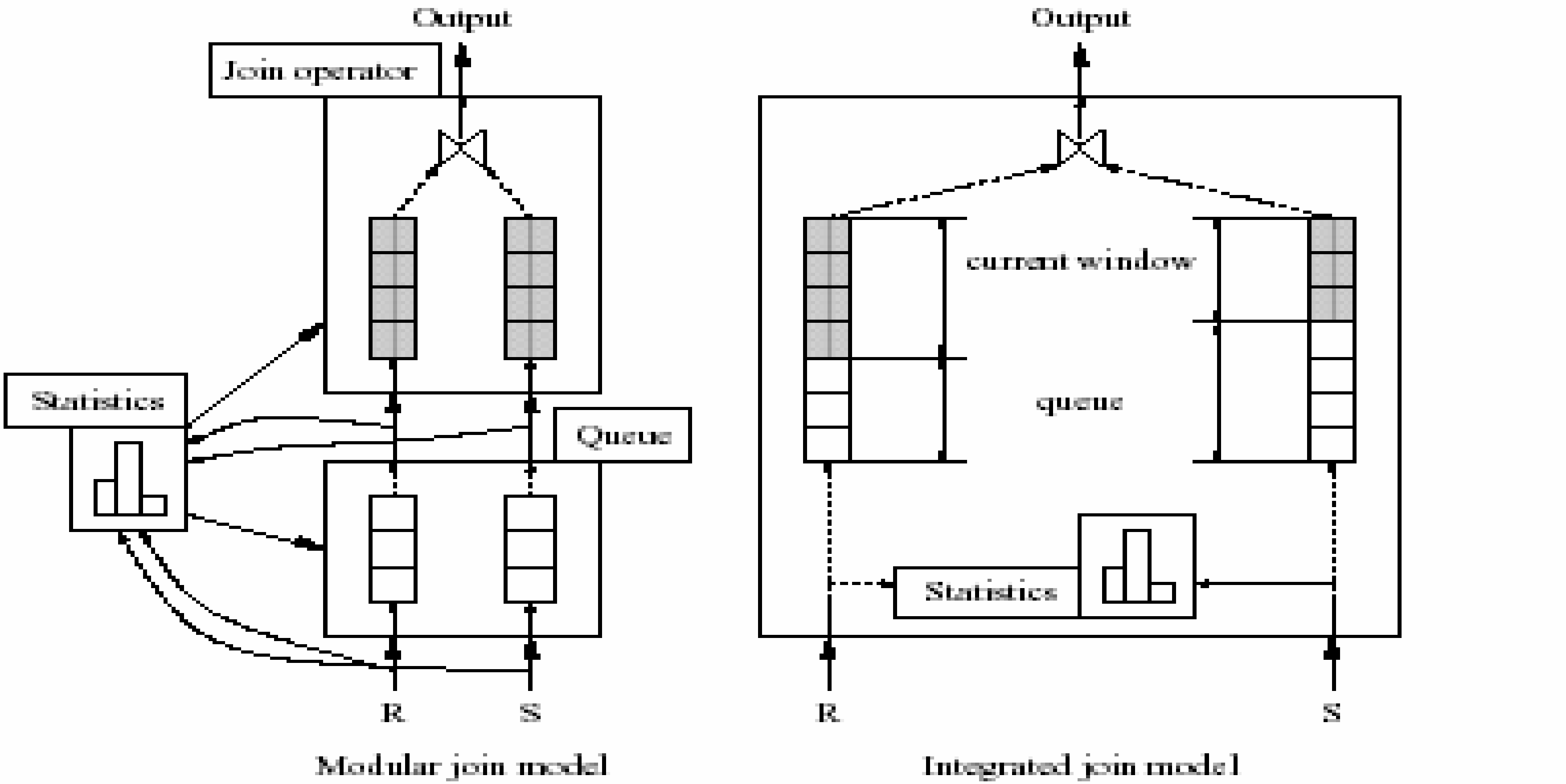


Figure 1: Join processing models

- Fast CPU vs. Slow CPU

Error Measures

- MAX-Subset Measure
  - The Symmetric Difference : $|(X-Y)\cup(Y-X)|$
  - For equi-joins, dropping tuples before they expire naturally leads to the generated output being a subset of the exact join result
  - What the symmetric difference in this case implies?
- Archive-Metric (ArM) for Join with Archive Support
  - Observation: Streams are not always arriving at a consistently high rate!

$\delta_R(i,j)=1$ If r(i) survived for at least j time in memory, 0 otherwise

$$S^{<}(i)=\{j : j\in[i-w+1,i-1]\wedge s(j)=r(i)\}$$

$$j_{r(i)}=\max\{j : j\in[i,i+w-1]\wedge s(j)=r(i)\}$$

$$\sum(\delta_R(i,j_{r(i)}-i)\prod_{j\in S^{<}(i)}\delta_S(j,j-i)+\delta_S(i,j_{s(i)}-i)\prod_{j\in R^{<}(i)}\delta_R(j,j-i)))$$

MAX-Subset Measure – static case

- Aim: Find a set of k tuples to be dropped from the input relation s.t. the size of the k-truncated join result is as large as possible
- Model as a graph problem, bipartite graph G(Va, Vb,E)
  - Va Vb represent the two relations, each has one node for every tuple, an edge exists between two nodes if the corresponding tuples satisfy the join condition
  - G will consist of a union of mutually disjoin fully connected bipartite components (called Kurotowski components), represented as k(m,n)

MAX-Subset Measure – static case

- Input: A bipartite graph consisting of c mutually disjoint Kurotowski subgraphsby the c integer paris K(m1,n1),K(m2,n2)…
- Output: A set of k nodes to be retained s.t. the subgraph induced by them has the highest number of edges among all subgraphs with k nodes.

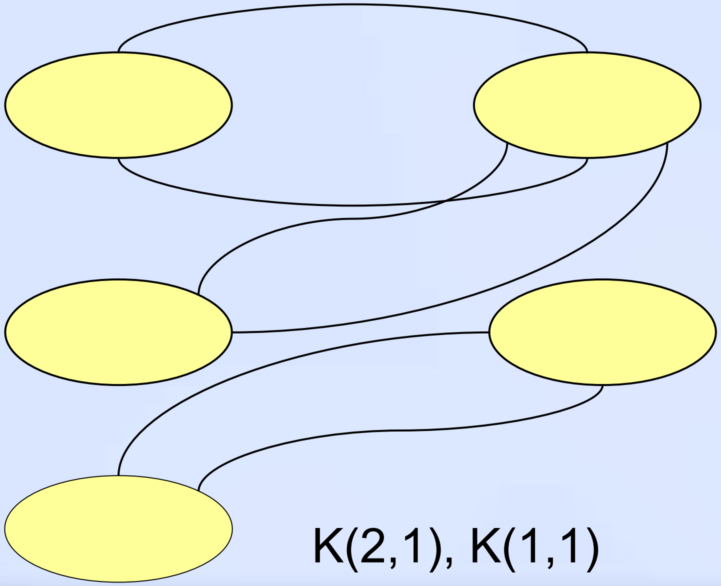
A	B
a	1
a	2
b	1

r

A	C
a	2
b	3

s

A	B	C
a	1	2
a	2	2
b	1	3



K(2,1), K(1,1)

MAX-Subset Measure – static case

- An Optimal Dynamic Programming Solution
  - Given k(m,n), m'*n' as large as possible, so m'+n'=p and |m'-n'| as small as possible
  - P nodes can be retained by chosen one by one from each partition. Cm,n (p) " max num. of edges can be retained when p nodes are retained from k(m,n)

$$C_{m,n}(p) = \begin{cases} (p/2)^2 & \text{if } p \le 2n,\ p \text{ even} \\ (p^2-1)/4 & \text{if } p \le 2n,\ p \text{ odd} \\ n(p-n) & \text{else.} \end{cases}$$

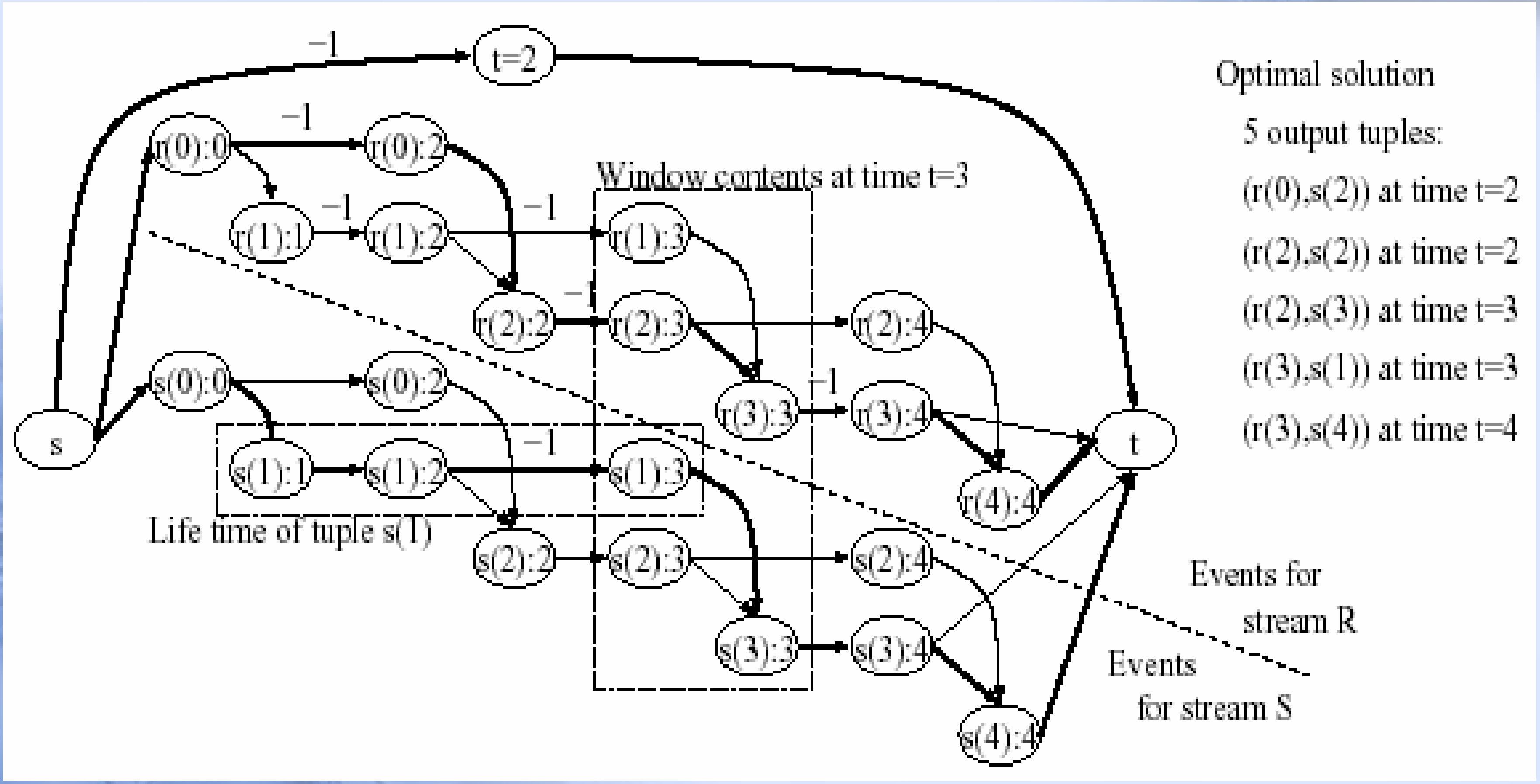
$$T(1,j) = \begin{cases} C_{m_1,n_1}(j) & \text{if } 0 \le j \le m_1+n_1 \\ -\infty & \text{if } j > m_1+n_1 \end{cases}$$

$$T(i,j) = \max \begin{cases} T(i-1,j), \\ T(i-1,j-1) + C_{m_i,n_i}(1), \\ T(i-1,j-2) + C_{m_i,n_i}(2), \\ \vdots \\ T(i-1,j-m_i-n_i) + C_{m_i,n_i}(m_i+n_i) \end{cases}$$

How about 3-relation static join load shedding problem?

MAX-Subset Measure - Fast CPU and offline

- OPT-Offline Algorithm based on Flow Graph
- The Flow Graph: R = 1,1,1,3,2 S = 2,3,1,1,3, M=2, w=3



(r(1),s(2)), (r(1),s(3)) missed!

MAX-Subset Measure - Fast CPU and offline

- Solving the linear minimum-cost flow problem for this graph produces the optimal strategy for deciding which tuples to drop from memory at each time instant!
- The highest absolute arc cost in network is 1, known algorithms find the optimal integer solution in time O(n*n*m*logn), m is num of arcs, n is num of nodes
- N: num of tuples in each stream, then total nodes will be 2wN+N+2 , total edges will be: (M+1+3*(numberNodes-2))

MAX-Subset Measure - Fast CPU and online

- PROB Heuristic
  - PROB estimates for each value in the domain of the join attribute the probability of a tuple with this value arriving on stream R and S.
  - The priority for r(i) is Ps(r(i)), ties are broken by giving higher priority to the tuple that arrived later
  - Favors high partner arrival probabilities over age.
  - How to compute Pr() and Ps() without knowing the future?
- LIFE Heuristic
  - Priority is t*Ps(r(i)), t is the remaining lifetime of r(i).

Which one is better?

Experiments

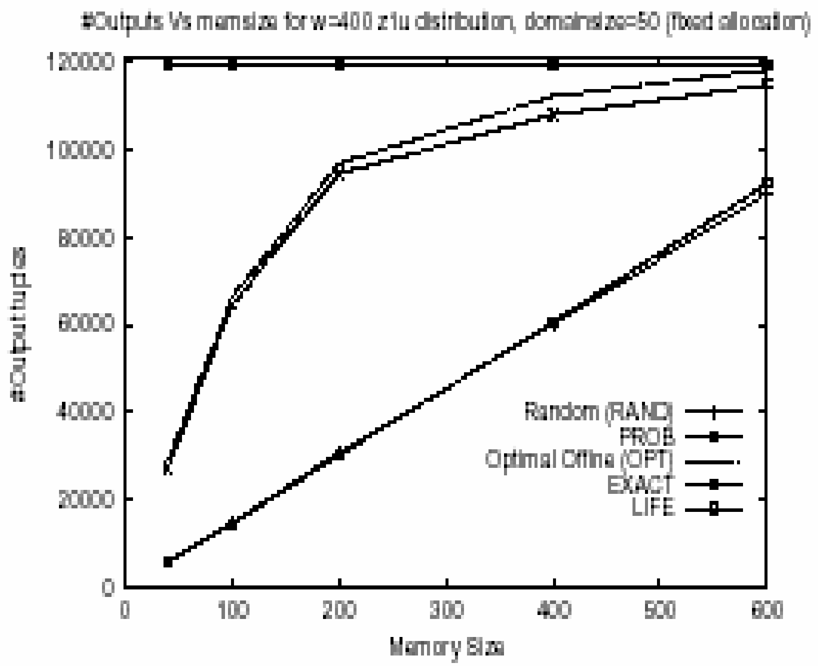


Figure 3: Window size 400

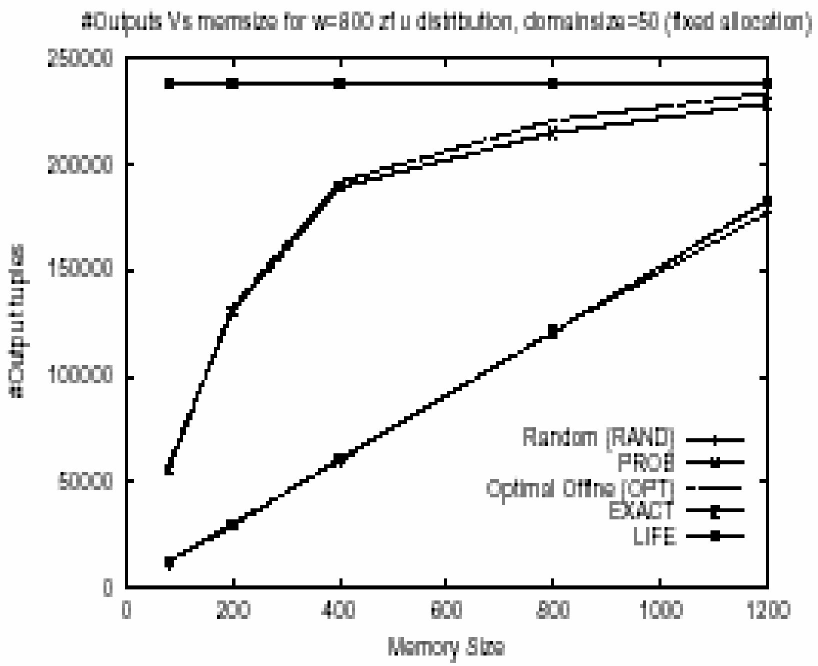


Figure 4: Window size 800

Experiments

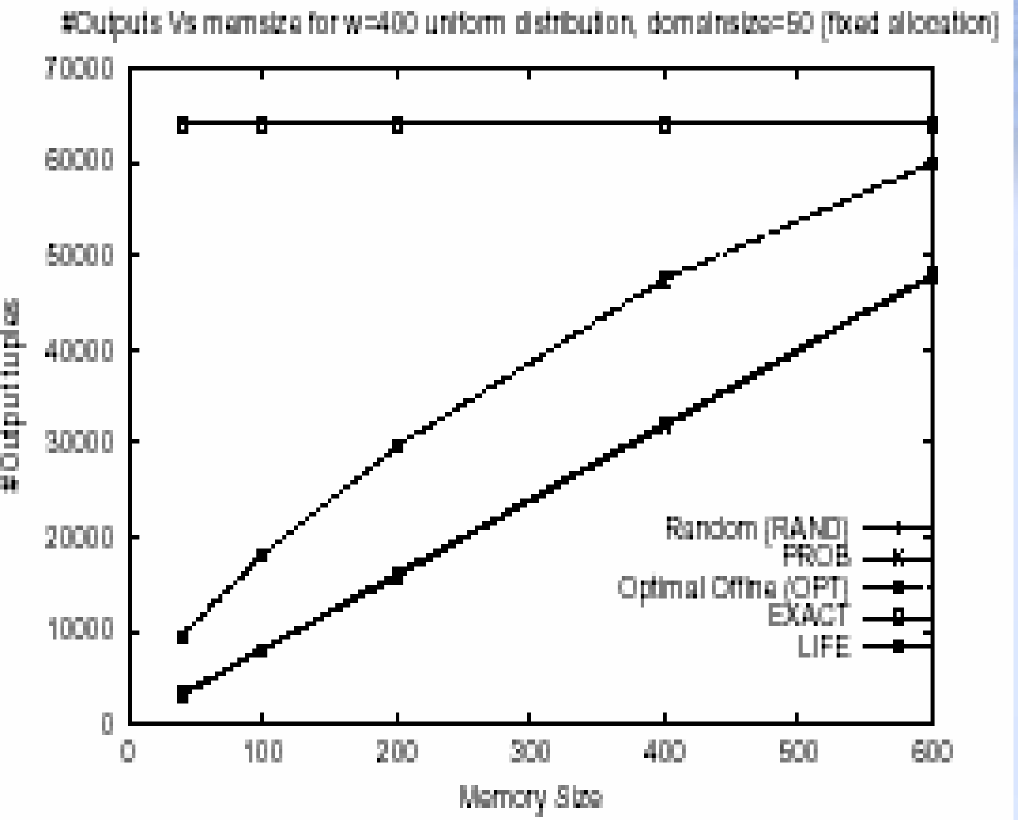


Figure 5: Uniform input

Experiments

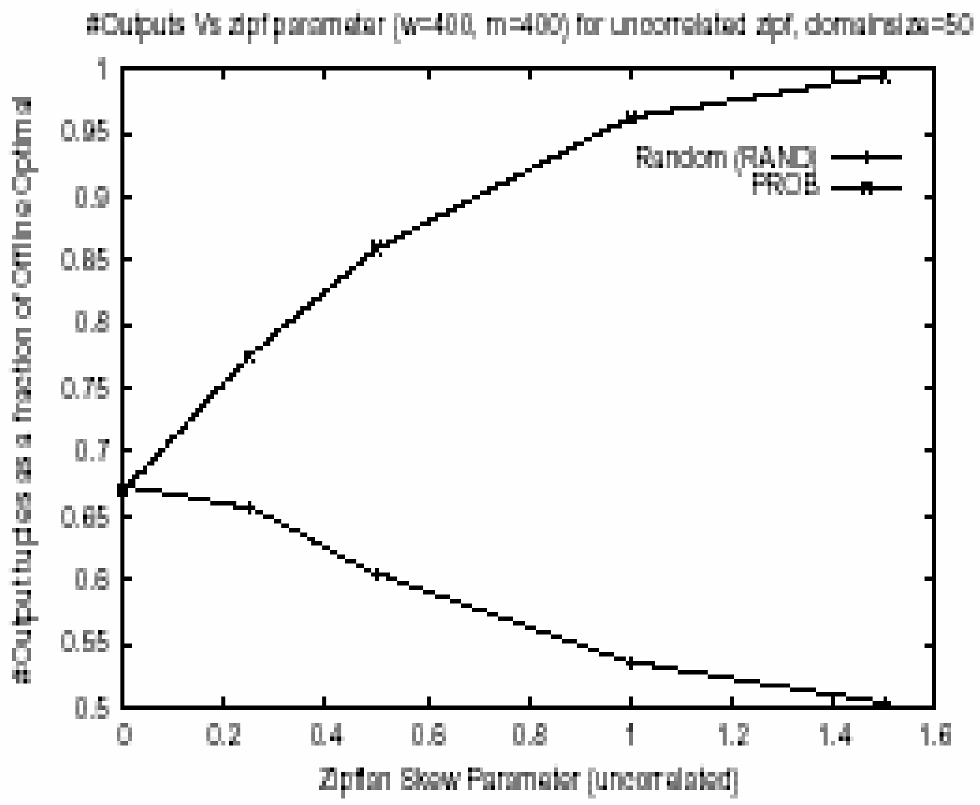


Figure 6: Uncorrelated Zipf

Experiments

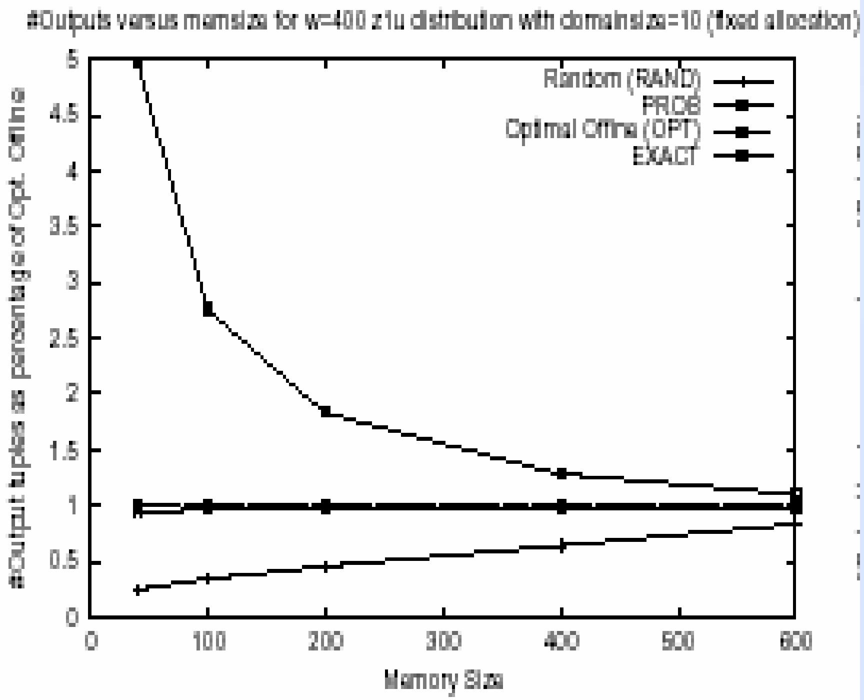


Figure 9: Domain size 10

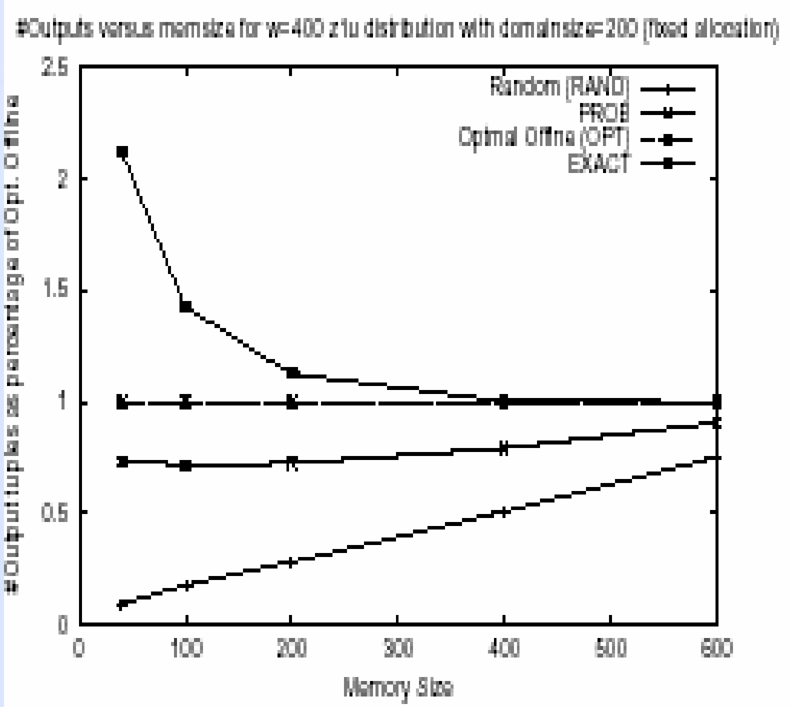


Figure 11: Domain size 200

Conclusion

- Carefully designed Semantic Load Shedding Algorithm is much better than random load shedding
- Problems:
  - How about Archive-metric?
  - Slow CPU?
  - Even more streams?

Thanks!