Falcon: A Graph Manipulation Language for Heterogeneous Systems

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4. Supports parallel execution of different algorithms on multiple devices.
5. Supports partitioning of Graph objects and execution of a single algorithm using multiple devices. Used when graph object does not fit in a single device.
6. Supports mutation of Graph object.
7. Allows viewing Graph in different way(say collection of triangles).

Language constructs for parallelization and Synchronization in Falcon

single(t1) {stmt block1} **else** {stmt block2}	The thread that gets a lock on item t1 executes stmt block1 and other threads execute stmt block2.
single(coll) {stmt block1} **else** {stmt block2}	The thread that gets a lock on all elements in the collection executes stmt block1 and others execute stmt block2.

Table 1. single statement(Synchronization) in Falcon

Data Type	Iterator	Description
Graph	points	iterate over all points in graph
Graph	edges	iterate over all edges in graph
Graph	pptyname	iterate over all elements in new ppty.
Point	nbrs	iterate over all neighboring points
Point	outnbrs	iterate over dst point of outgoing edges (Directed Graph)
Edge	nbrs	iterate over neighbor edges
Set	item	iterate over all items in Set
Collection	item	iterate over all items in Collection

Table 2. Iterators for foreach(parallelization) statement in Falcon

parallel sections- for Multiple parallel regions on different devices.

After Last session of HiPEAC, you want to reach home through shortest path??!!

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1  int <GPU> changed = 0; // Variable on GPU
2  relaxgraph(Point <GPU>p, Graph <GPU>graph) {
3      foreach (t In p.outnbrs)
4          MIN(t.dist, p.dist + graph.getweight(p, t), changed);
5  }
6  main(int argc, char *argv[]) {
7      Graph hgraph; // graph on CPU
8      hgraph.addPointProperty(dist, int);
9      hgraph.getType() <GPU>graph; // graph on GPU
10     hgraph.read(argv[1]) // read graph on CPU
11     graph = hgraph; // copy graph to GPU
12     foreach (t In graph.points)t.dist=MAX_INT;//INFinity
13     graph.points[0].dist = 0; // source has dist 0
14     while( 1 ){
15         changed = 0;
16         foreach (t In graph.points) relaxgraph(t,graph);
17         if (changed == 0) break; //reached fix point
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19     for (int i = 0; i <graph.npoints; ++i)
20             printf("i=%d dist=%d\n", i, graph.points[i].dist);
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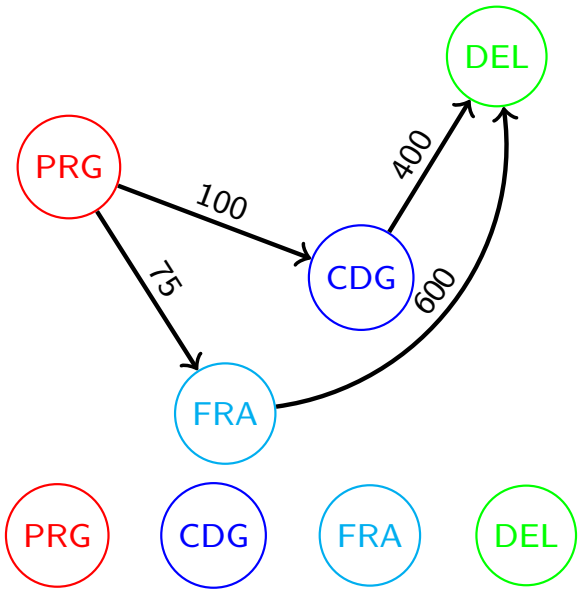

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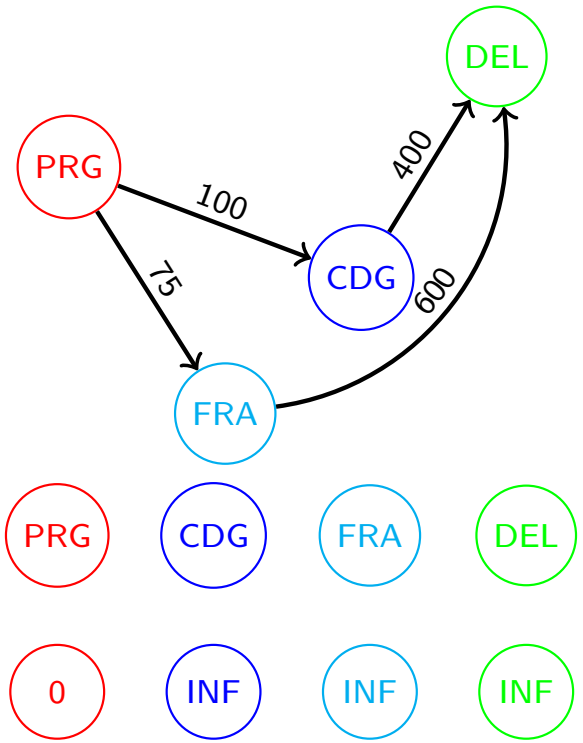

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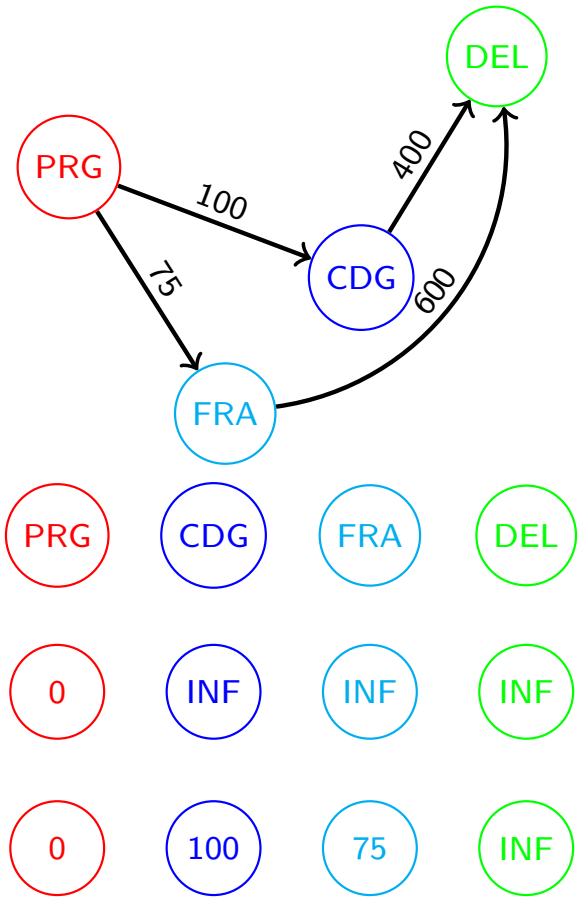

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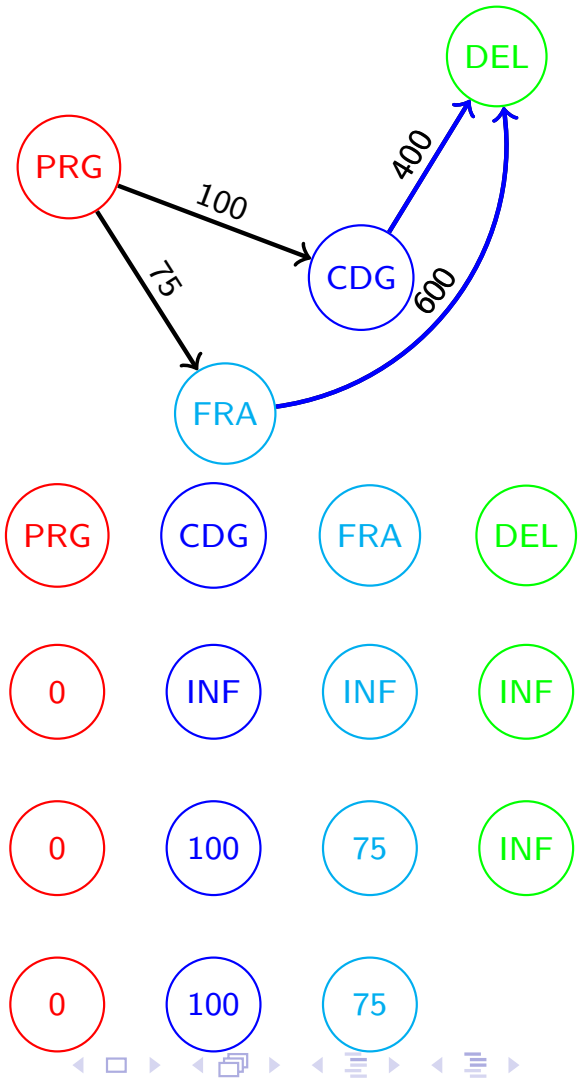

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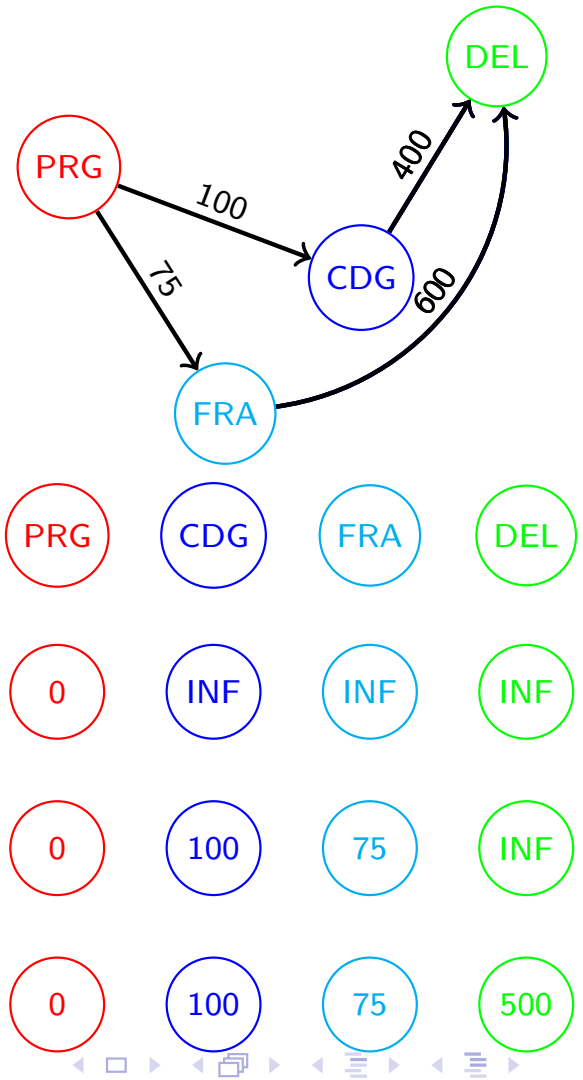

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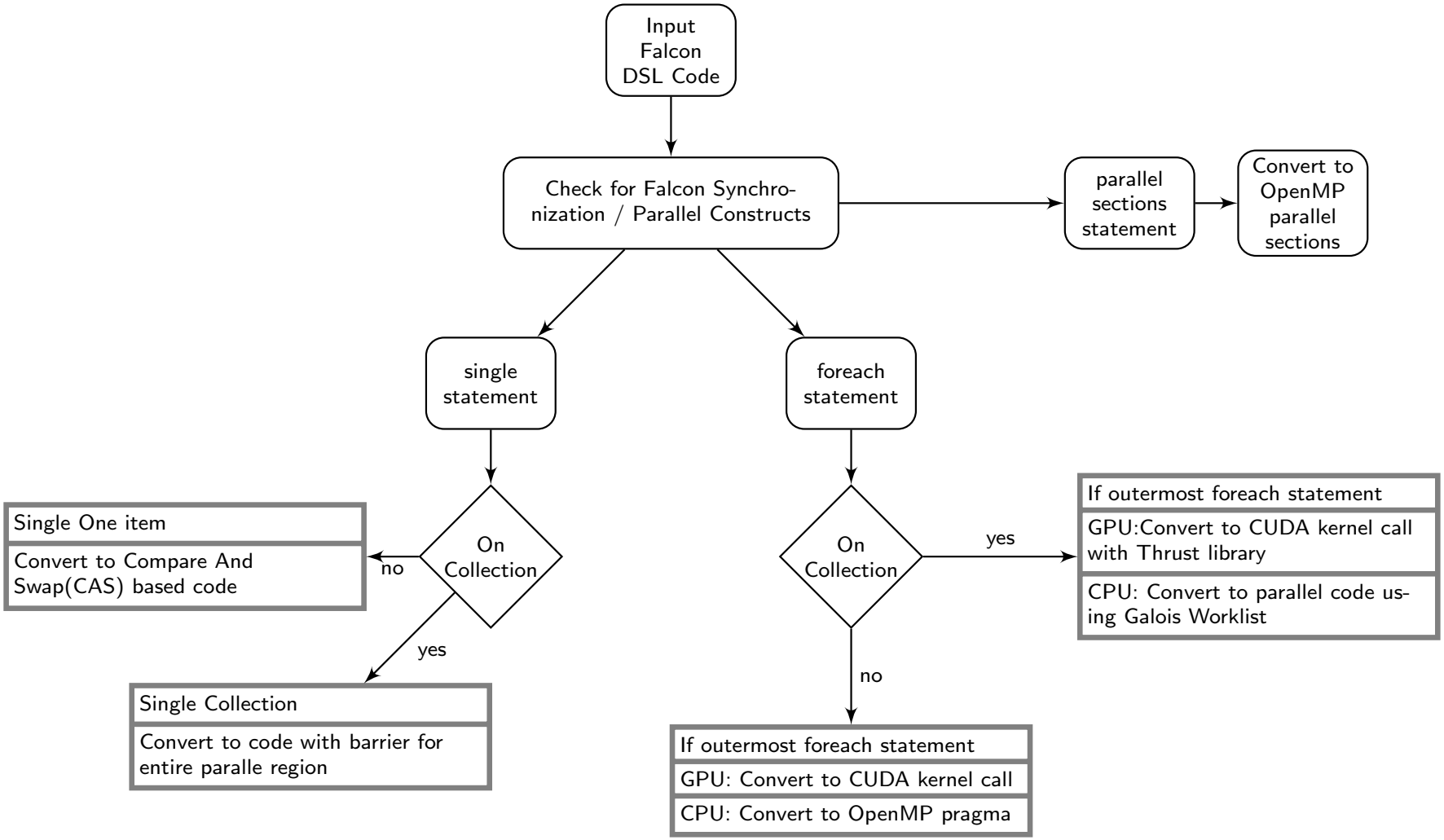

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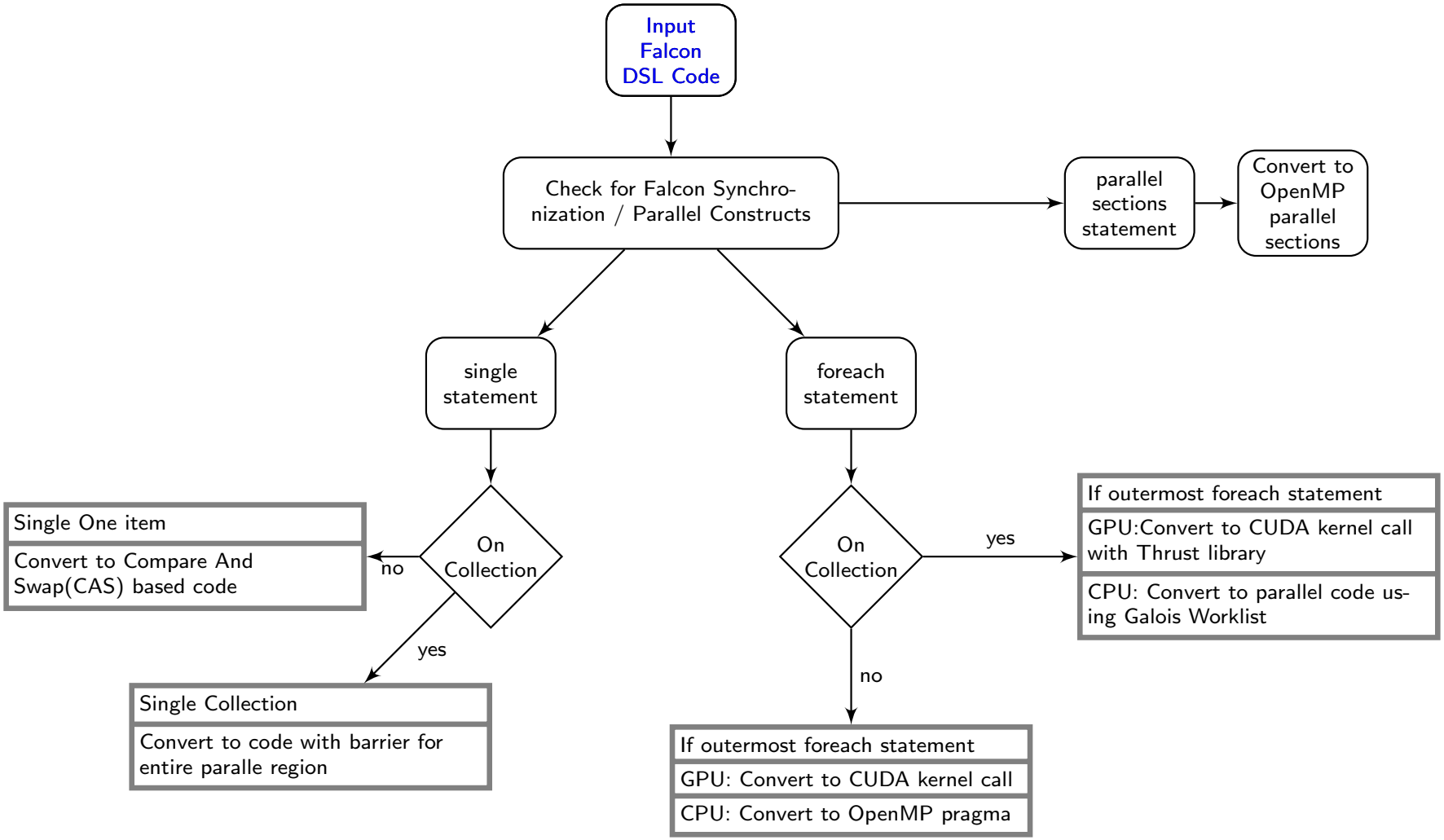

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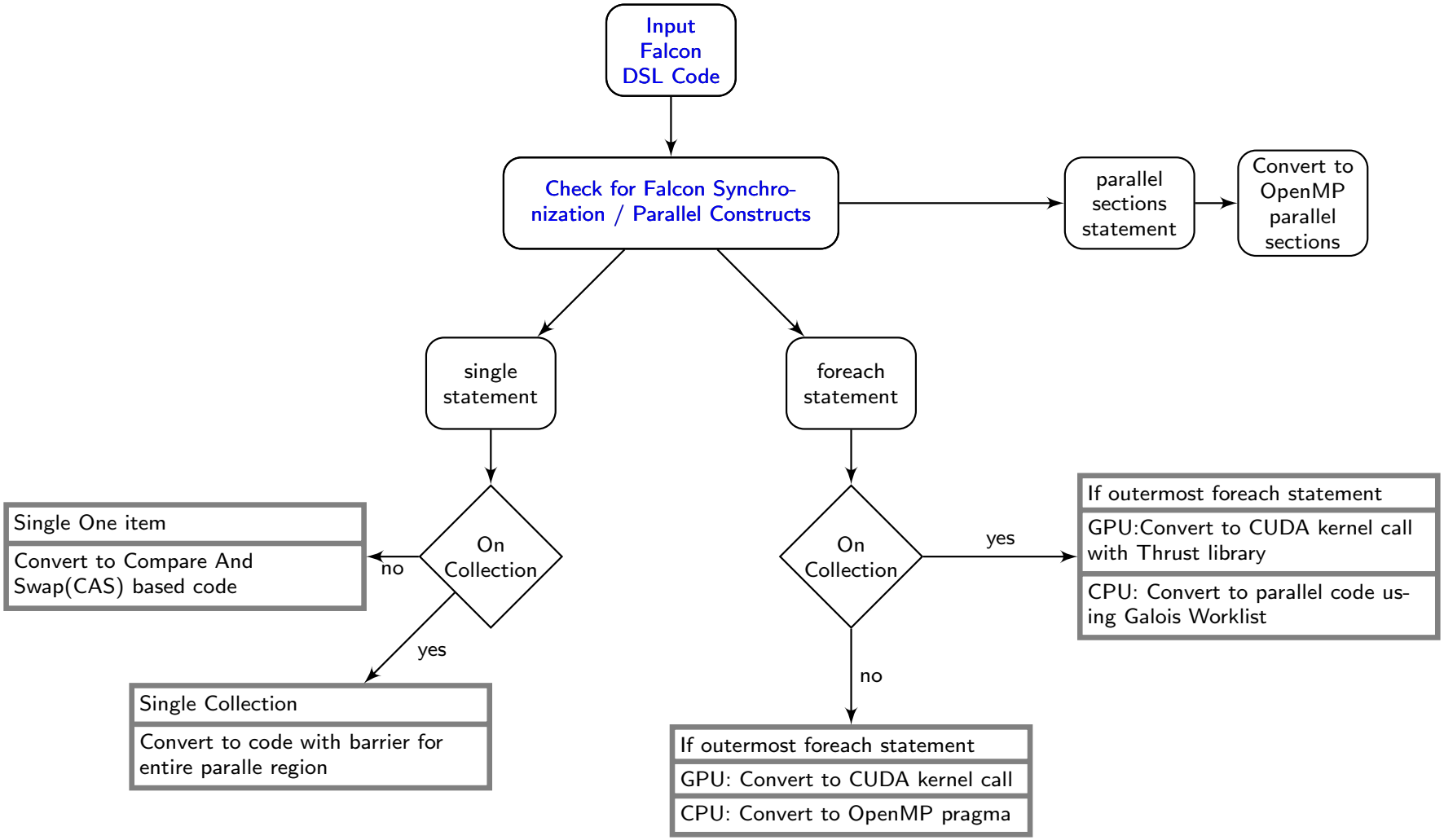

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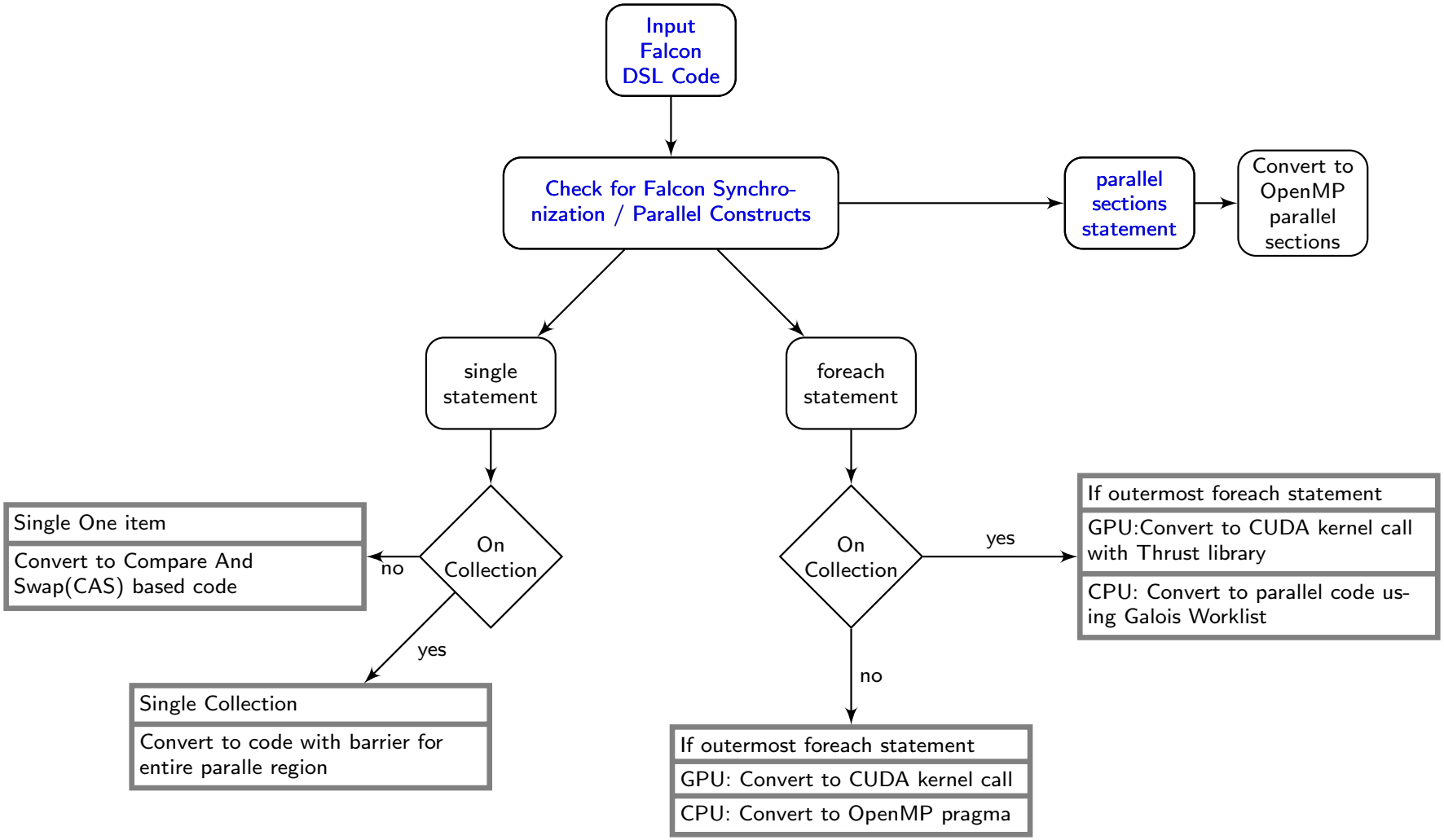

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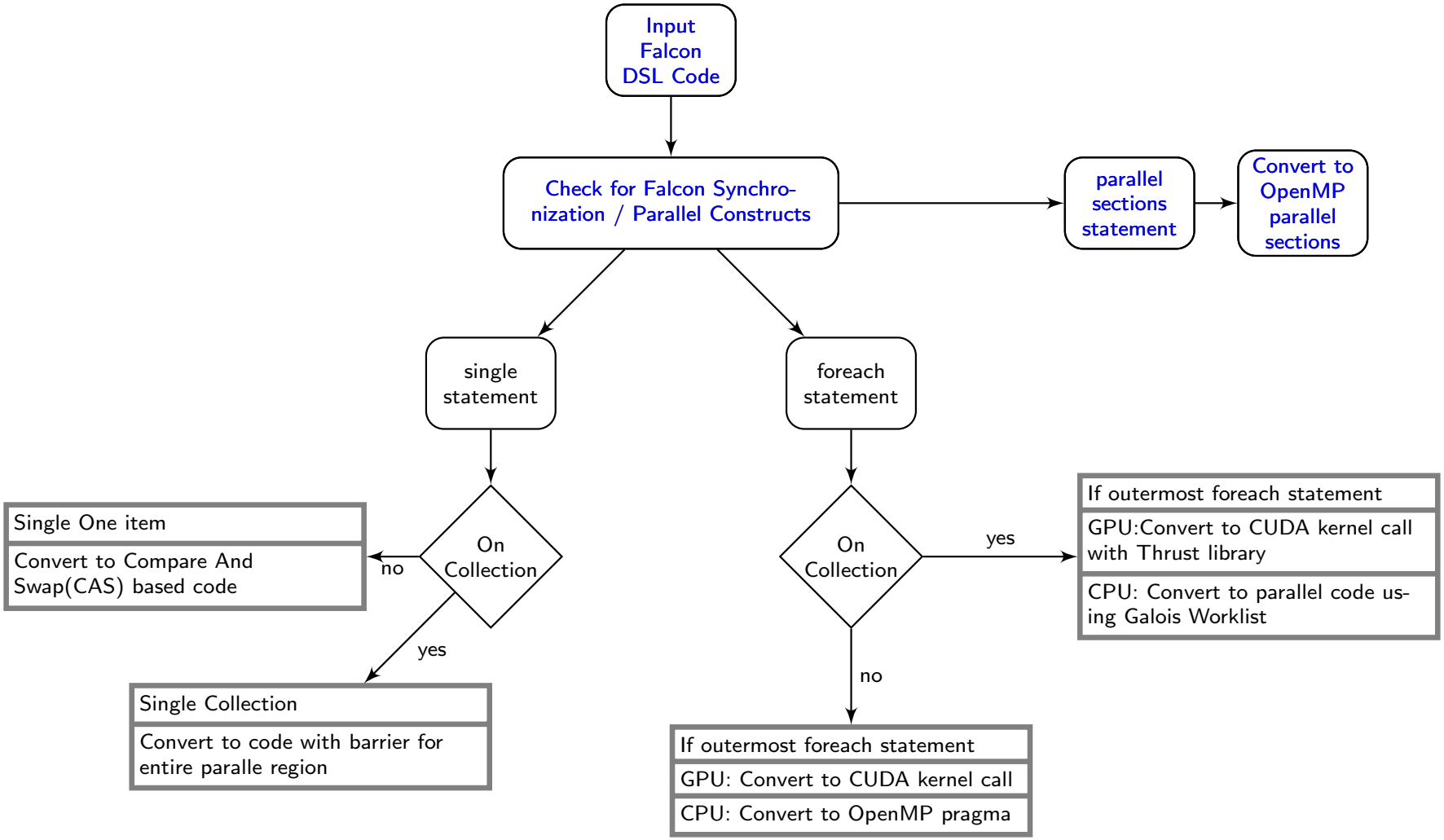

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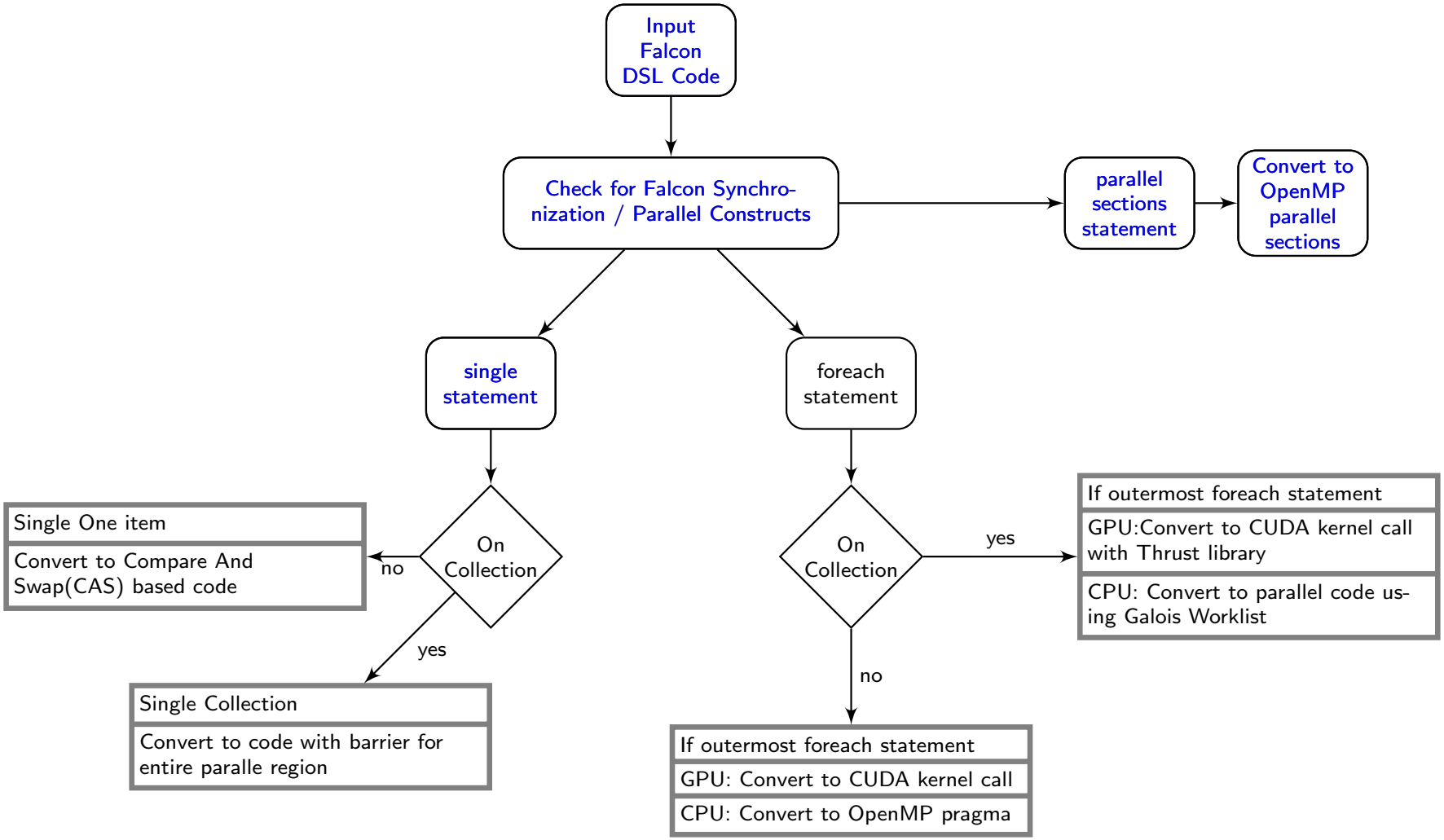

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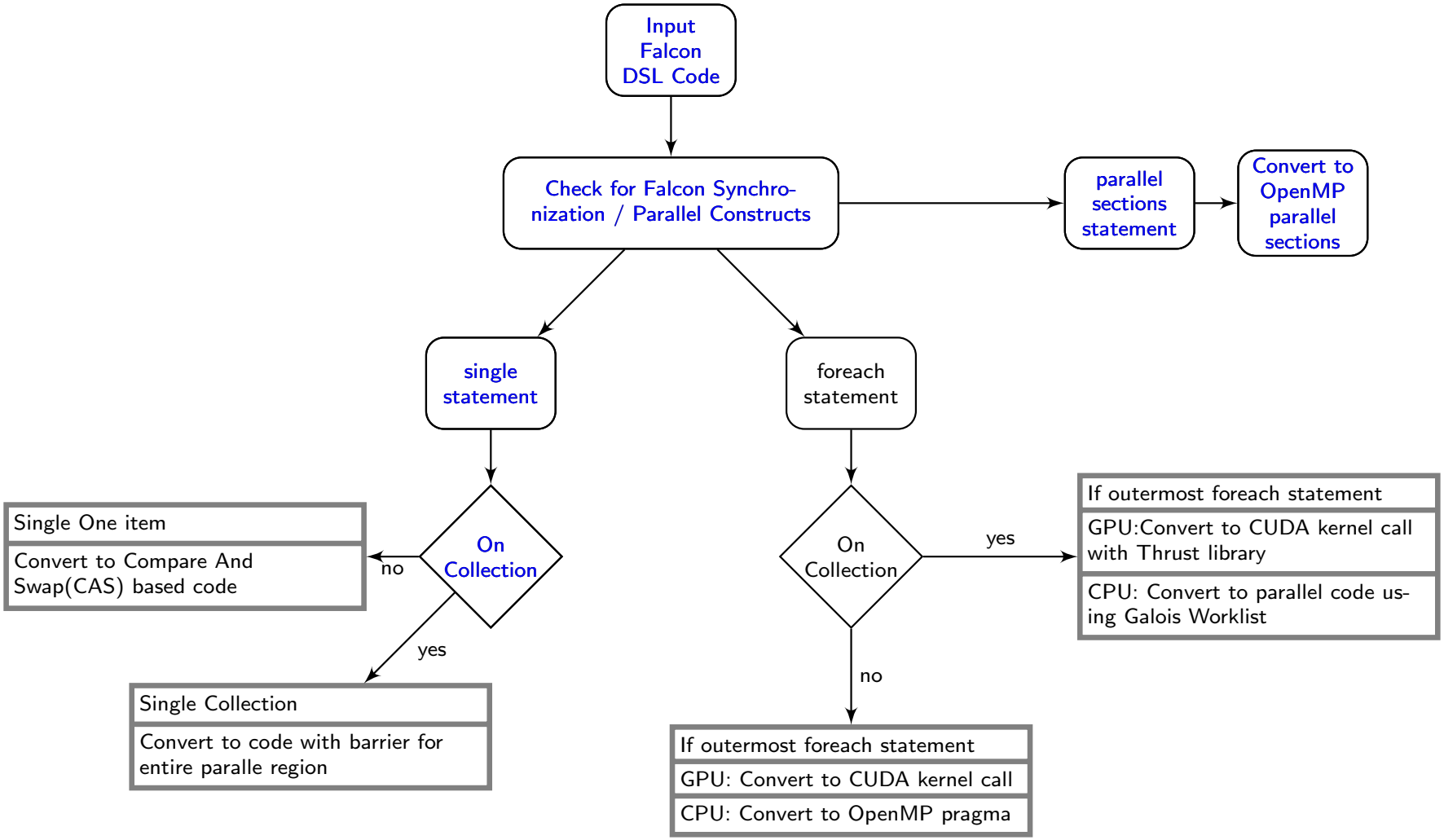

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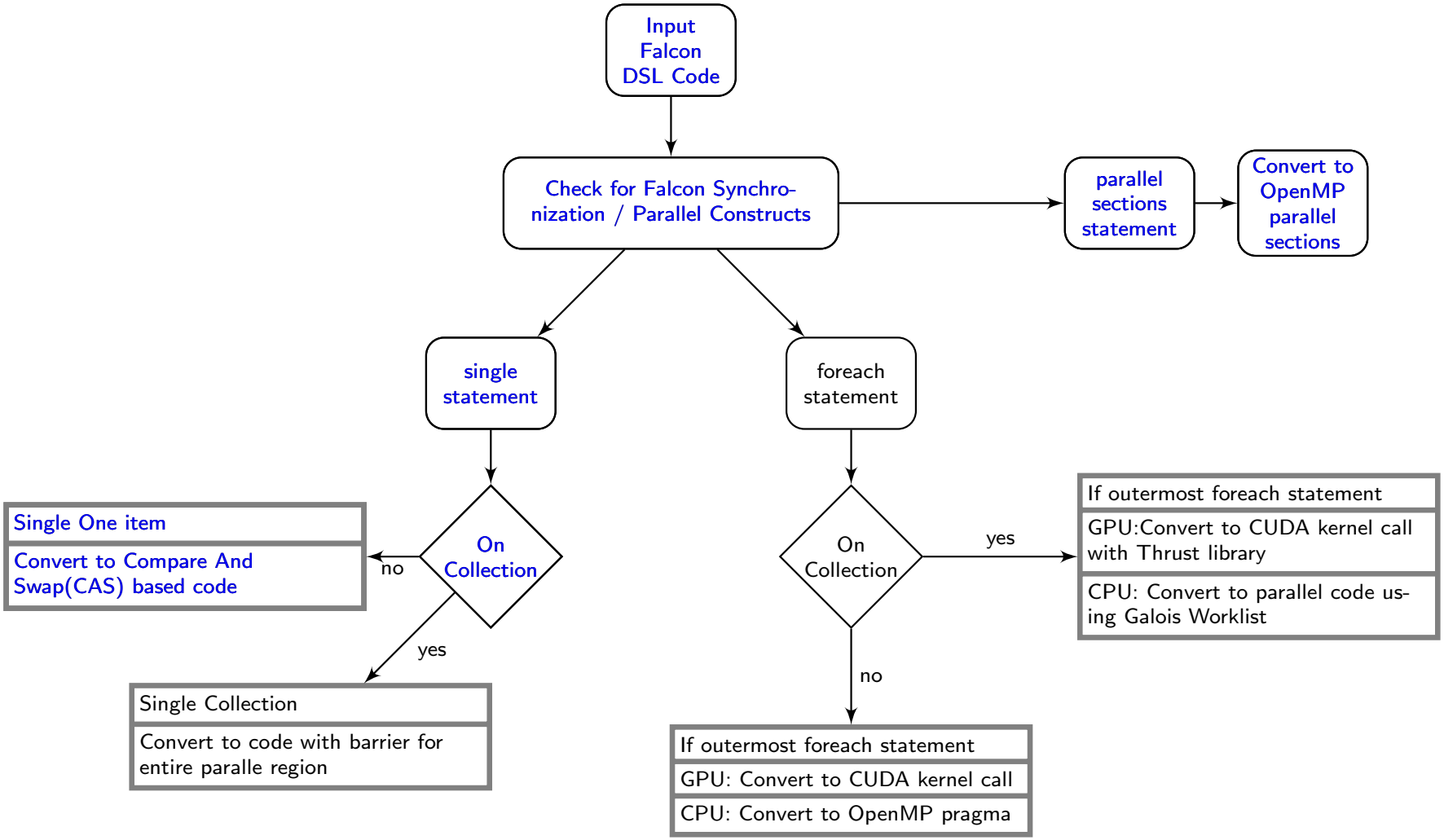

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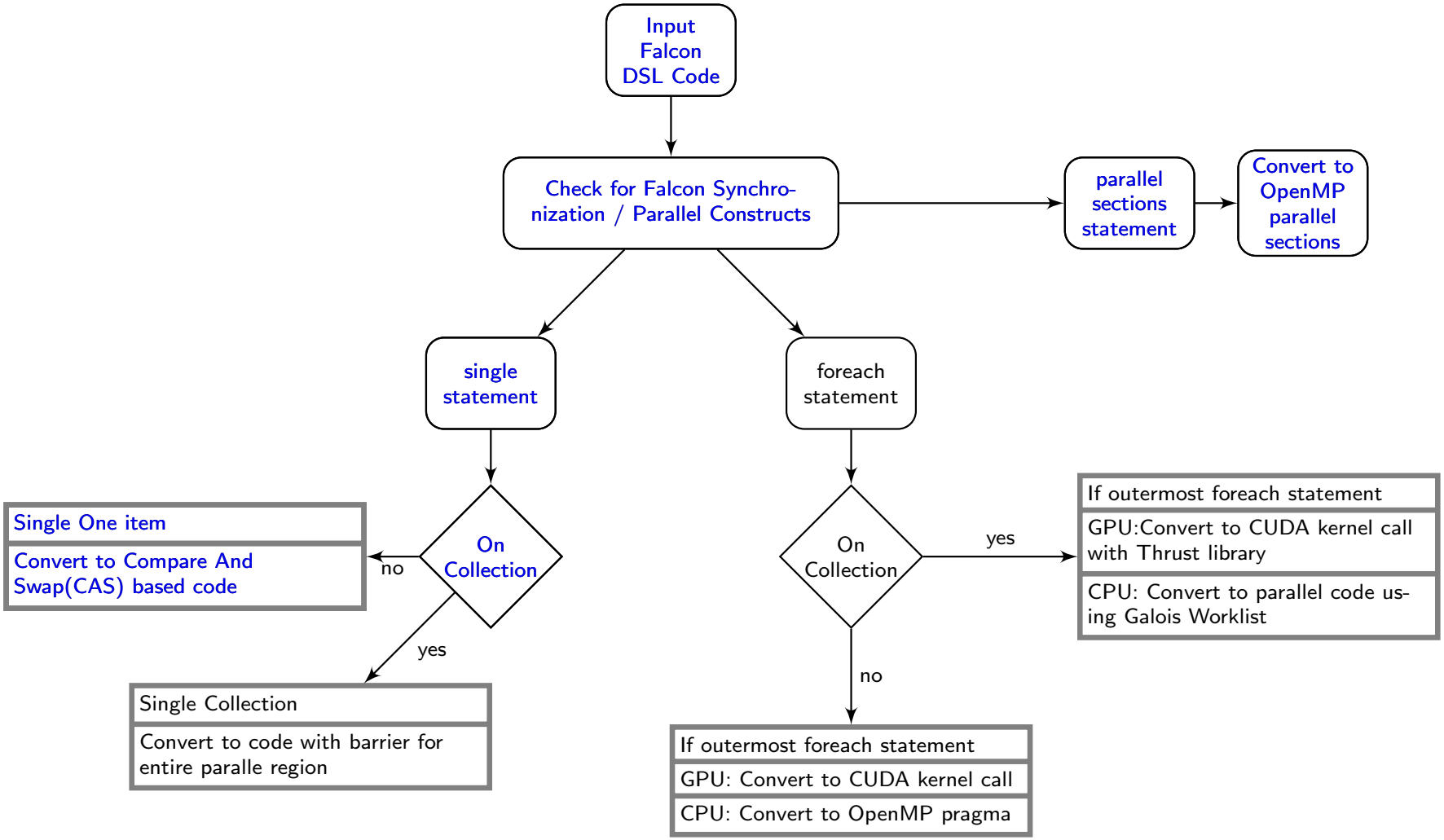

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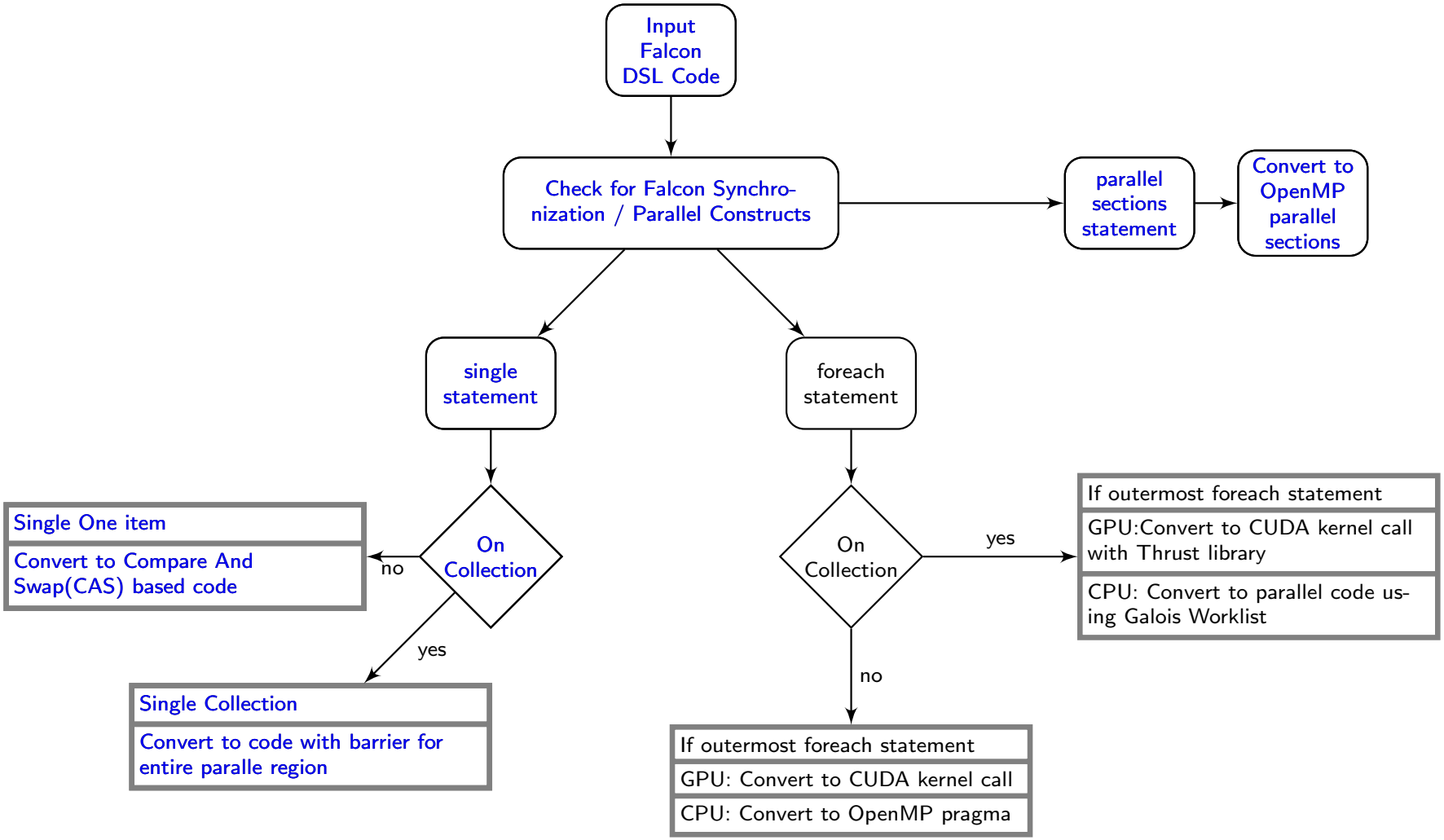

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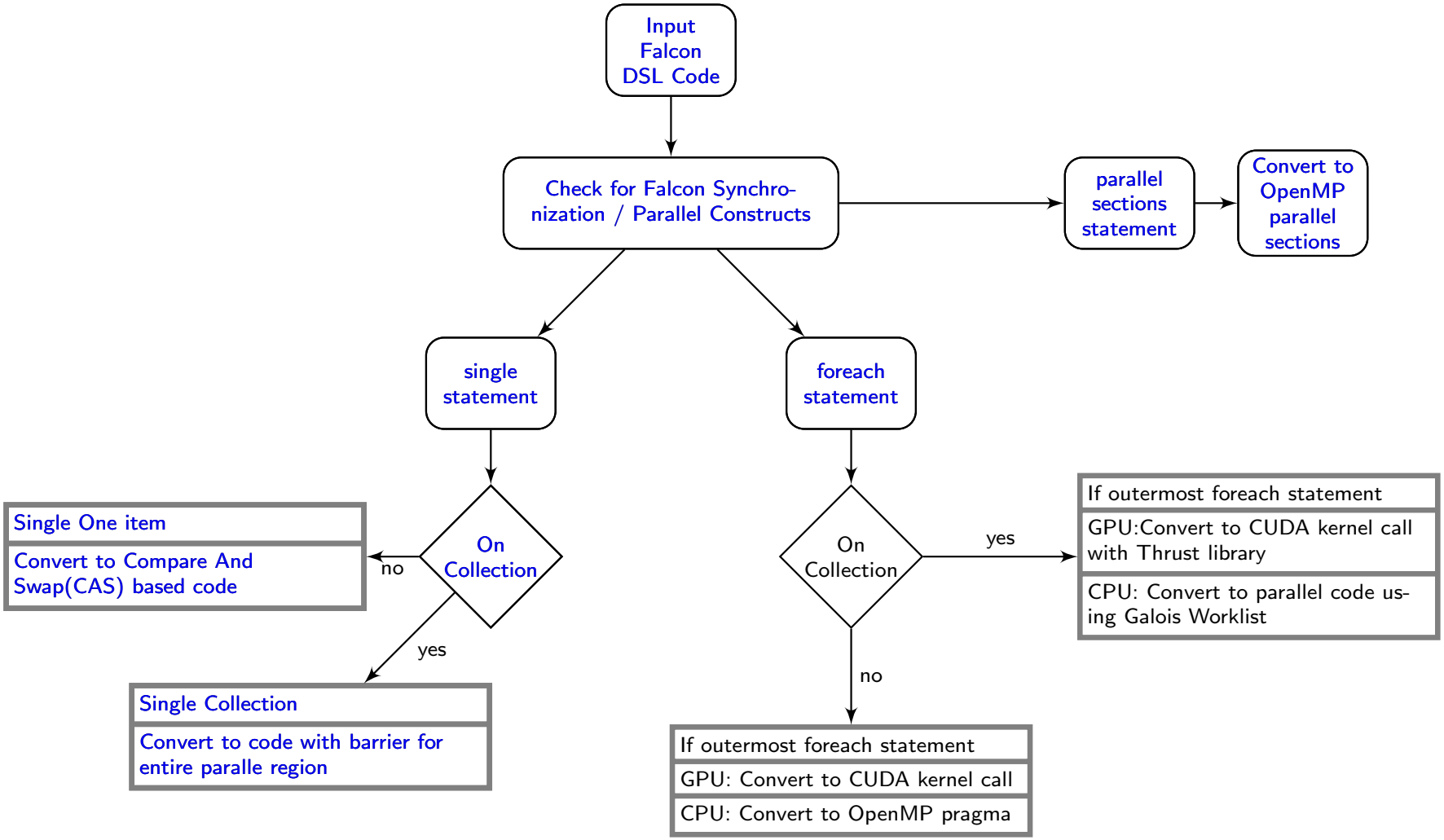

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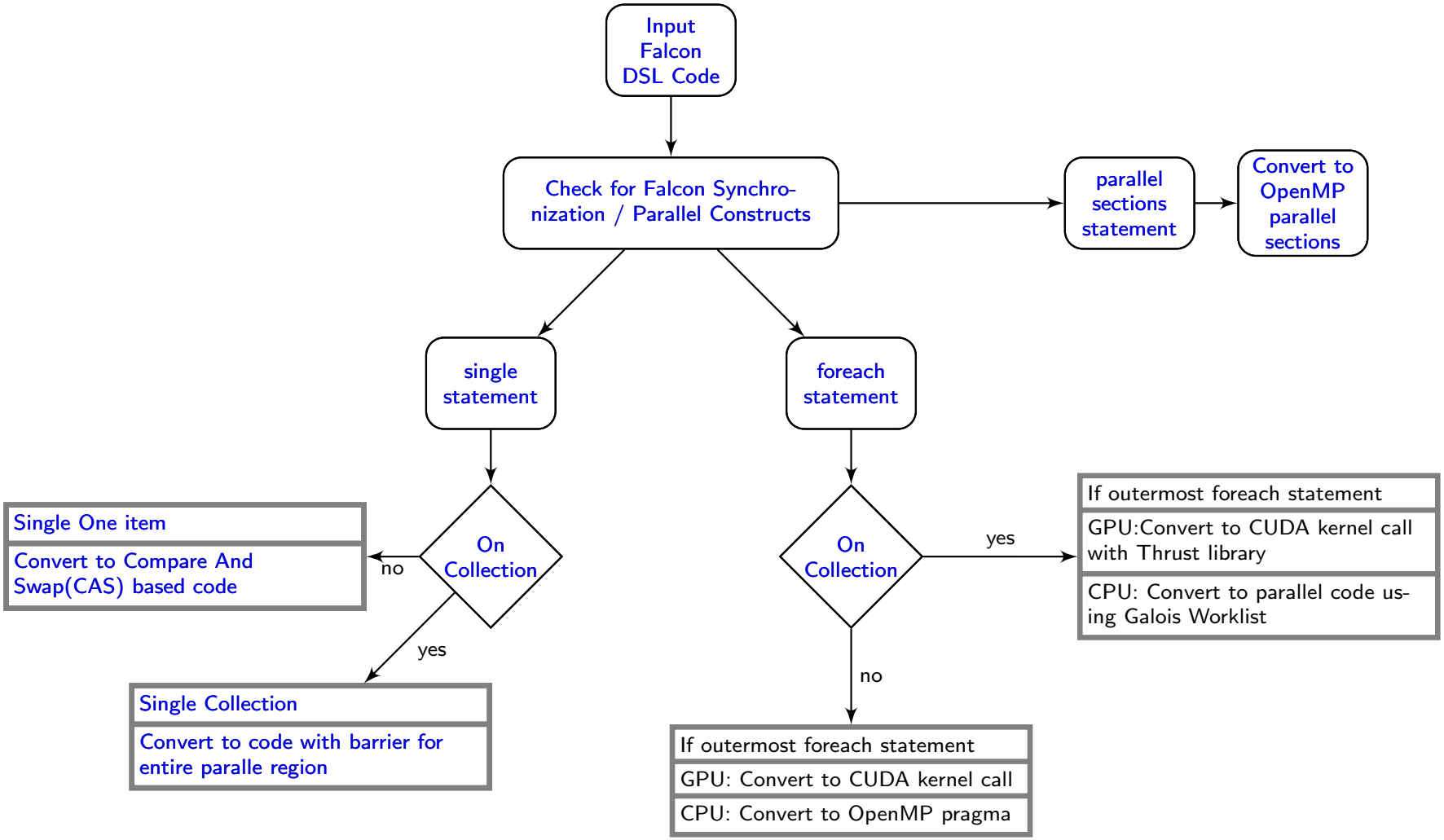

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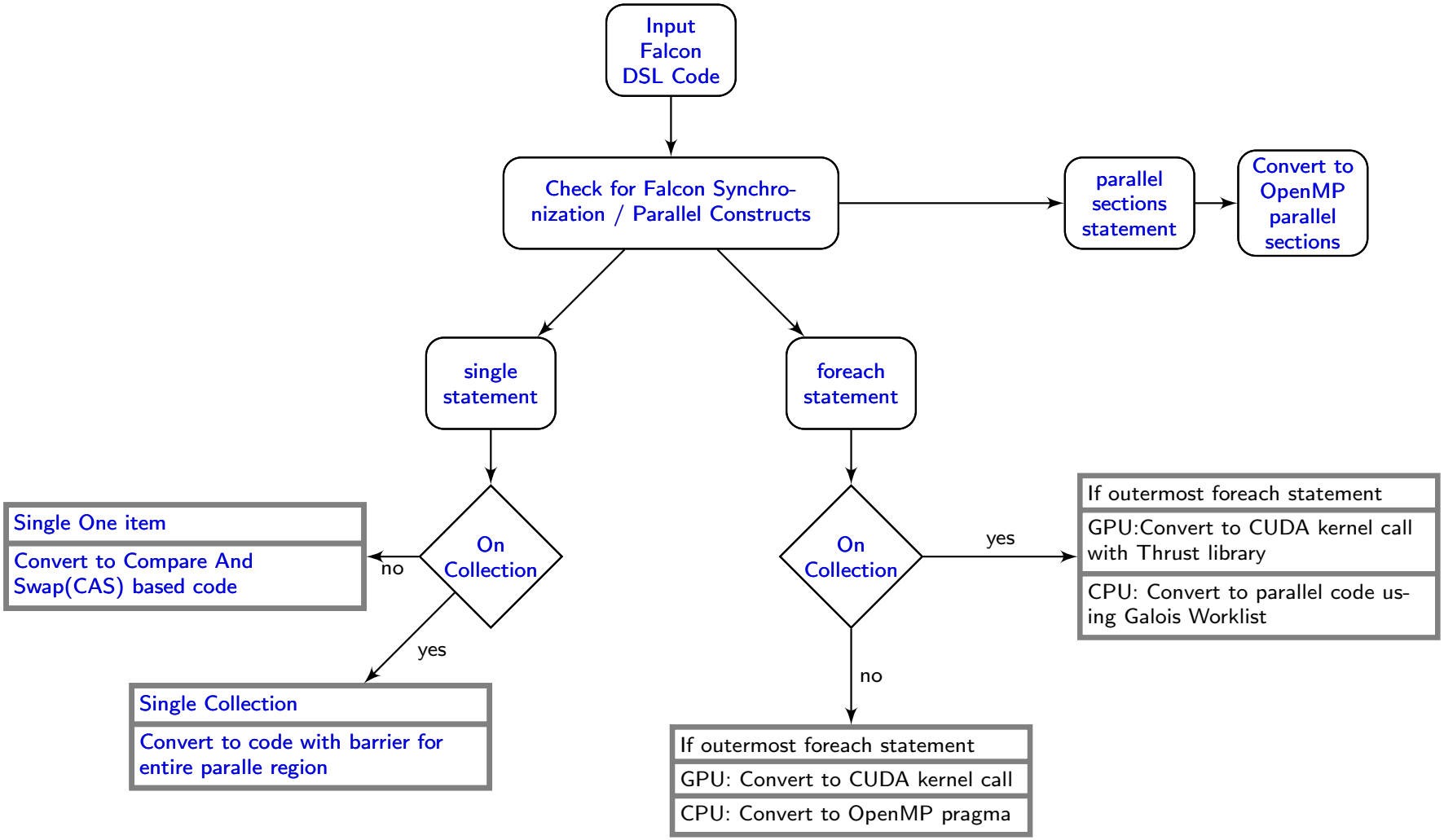

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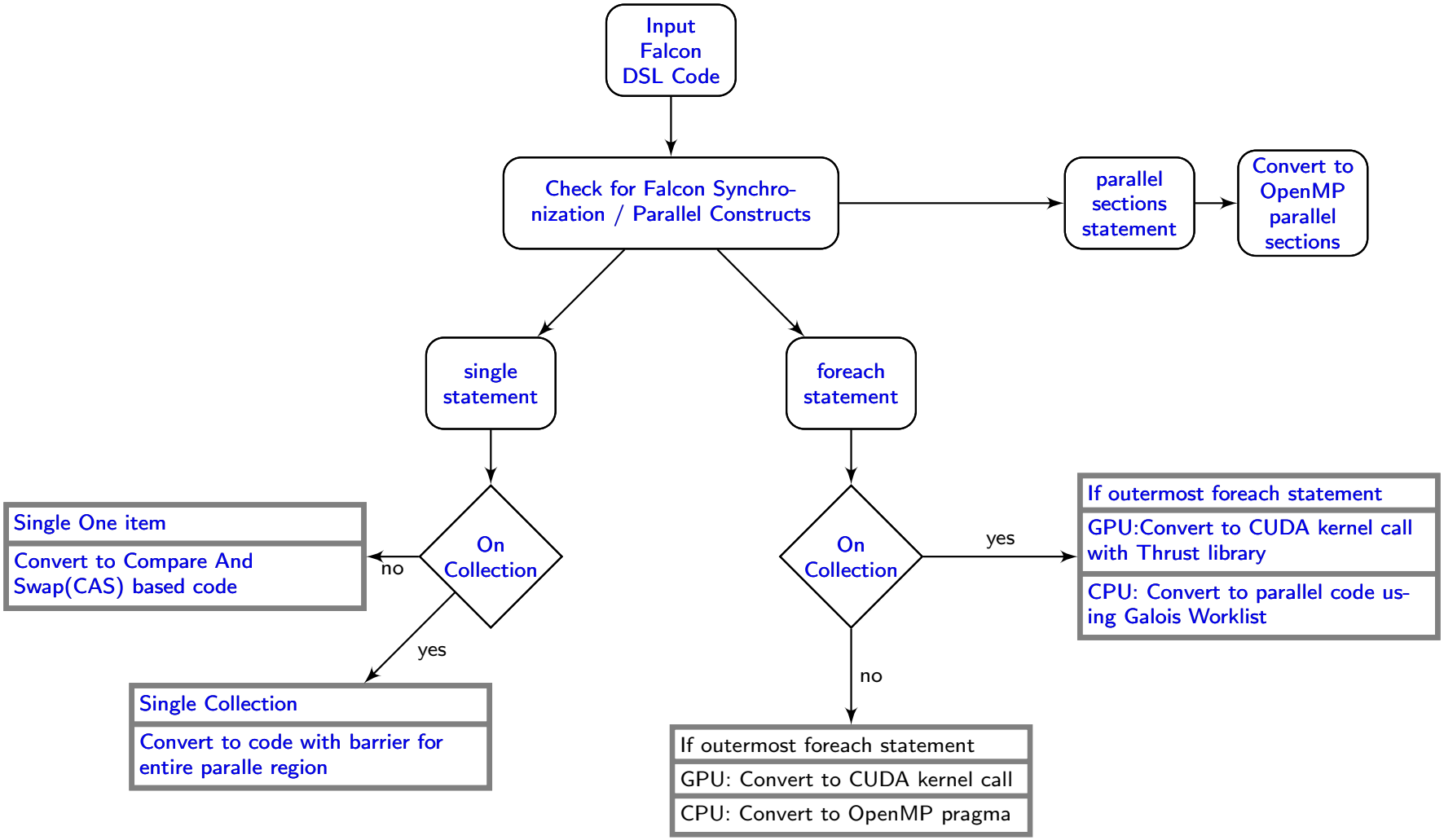

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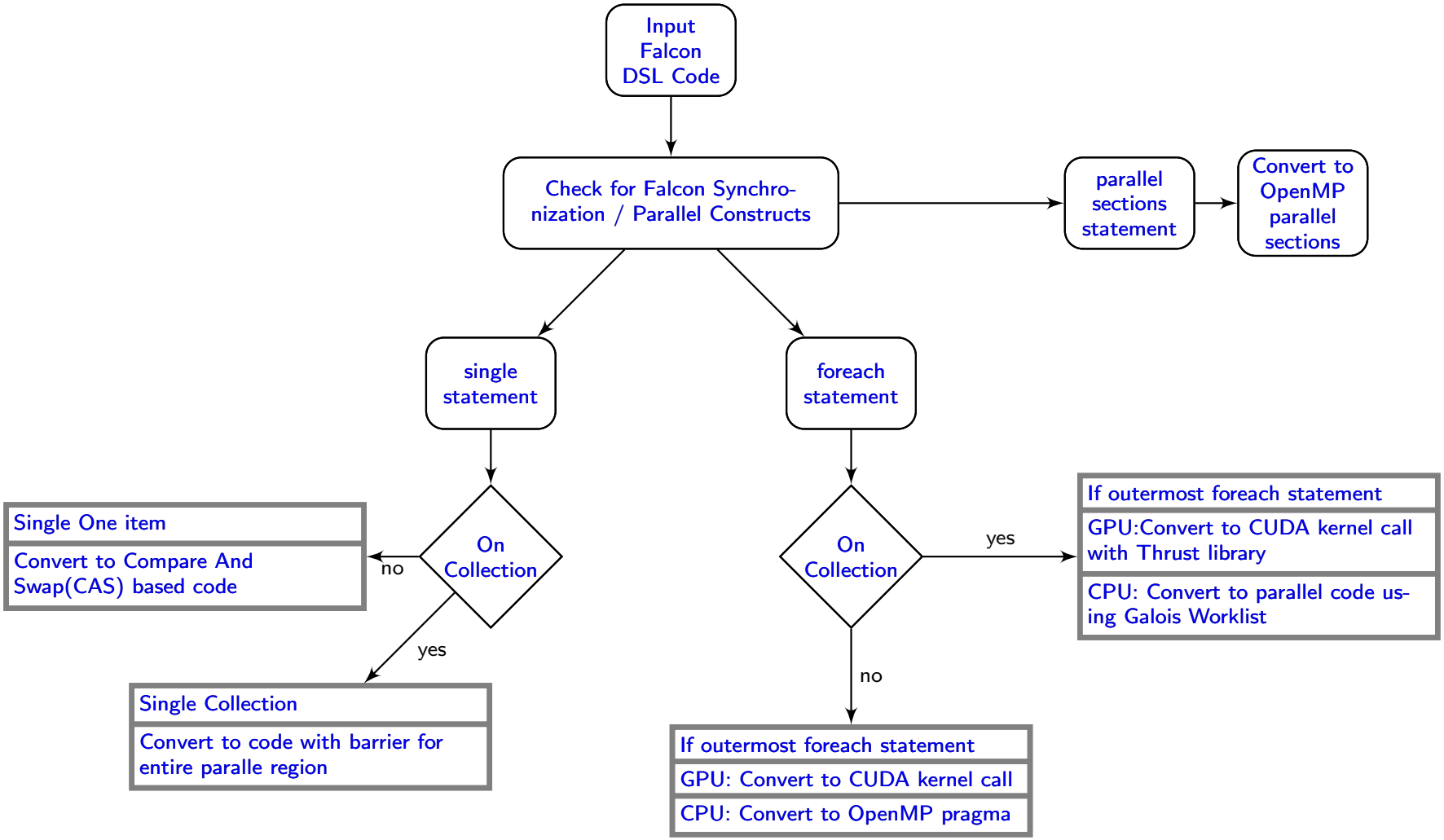

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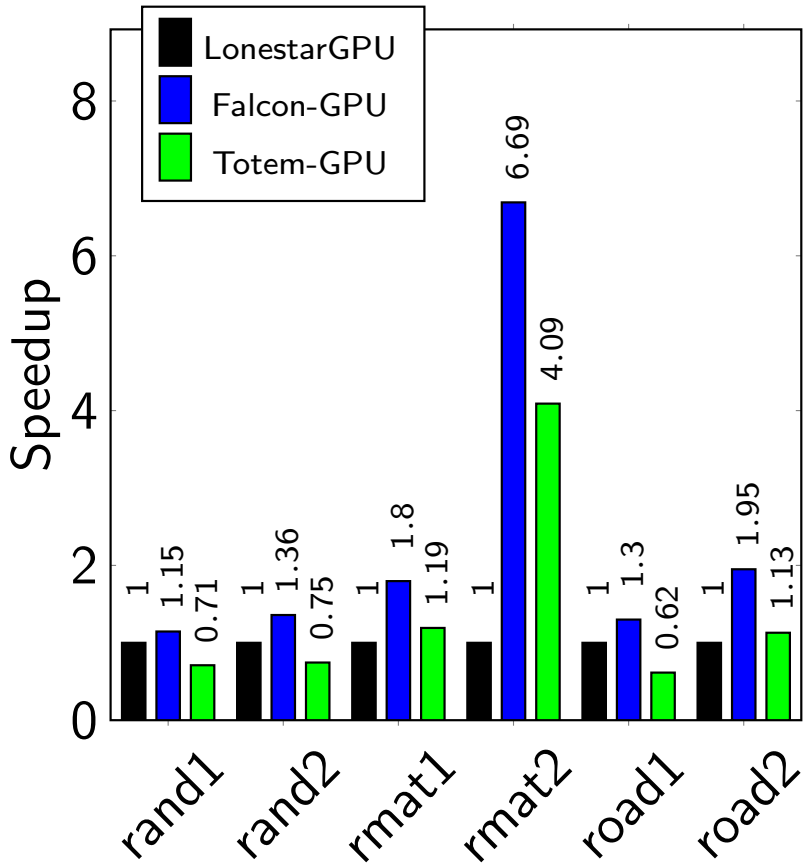
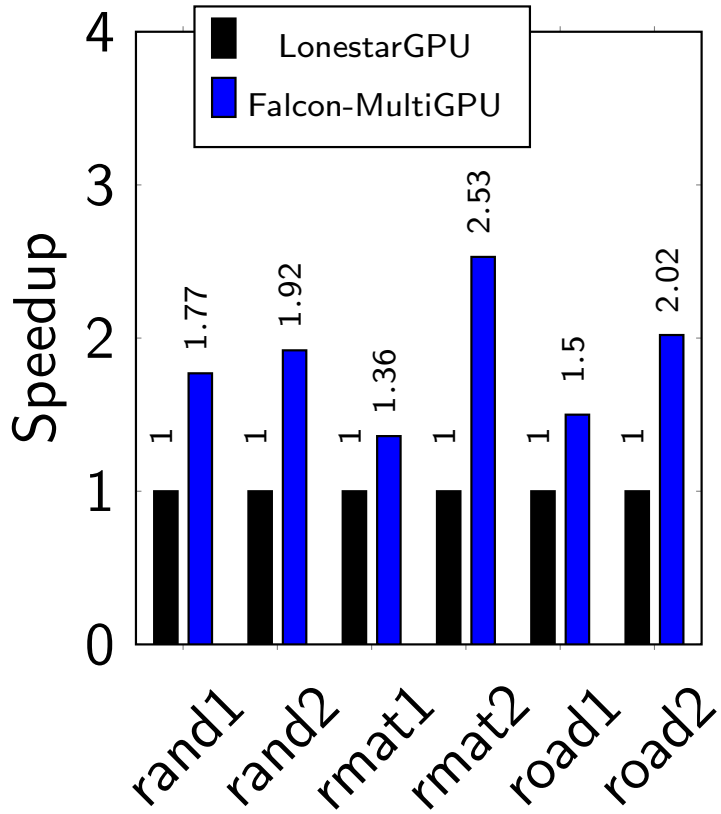
8. Tested on 12-core CPU and 4-GPU machine(1 Kepler and 3 Tesla).

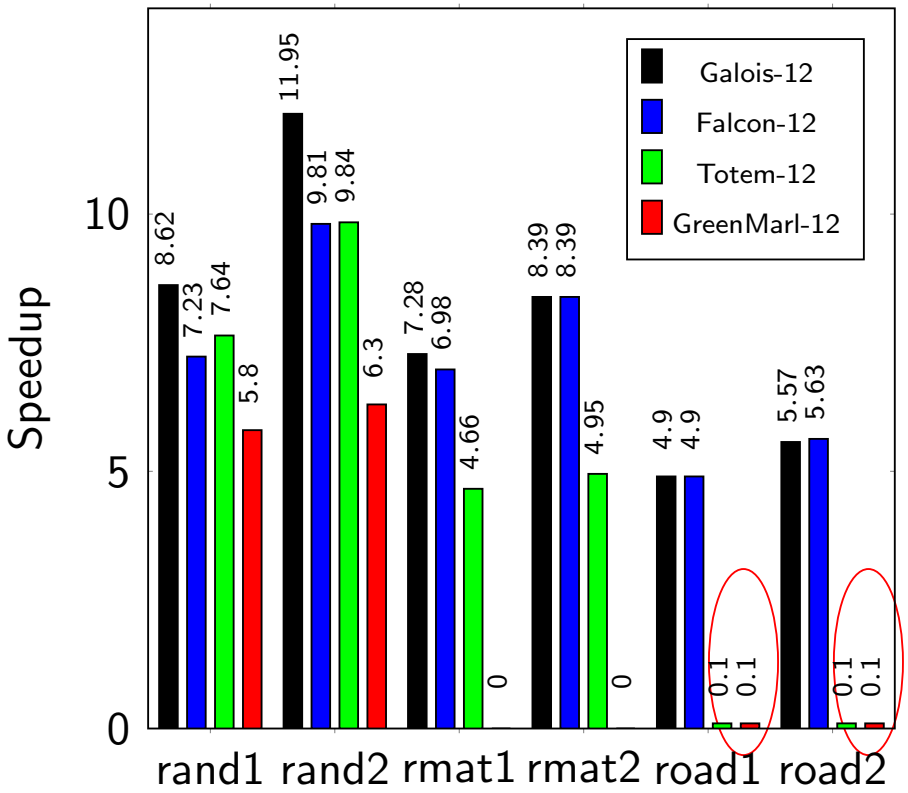
(Points,Edges) rand1(16M,64M),rand2(32M,128M)
rmat1(10M,100M),rmat2(20M,200M)
road1(14M,34M) road2(23M,58M)



Speedup of SSSP on GPU

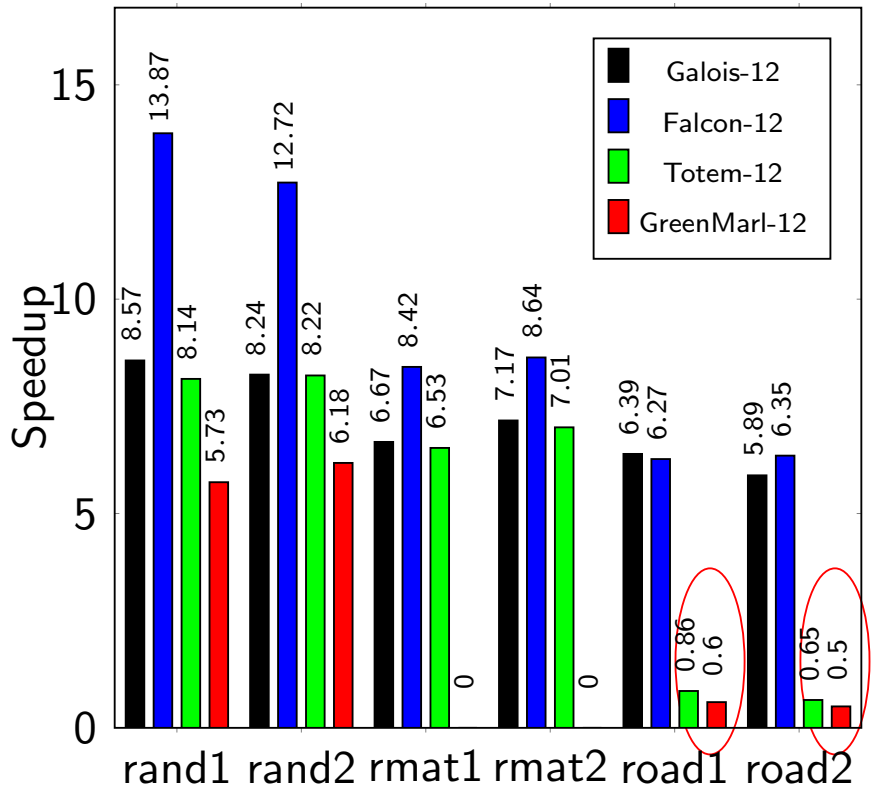


Speedup- SSSP, BFS and MST in parallel on 3 GPUs



(a)

SSSP speedup over Galois Single



(b)

BFS speedup over Galois single

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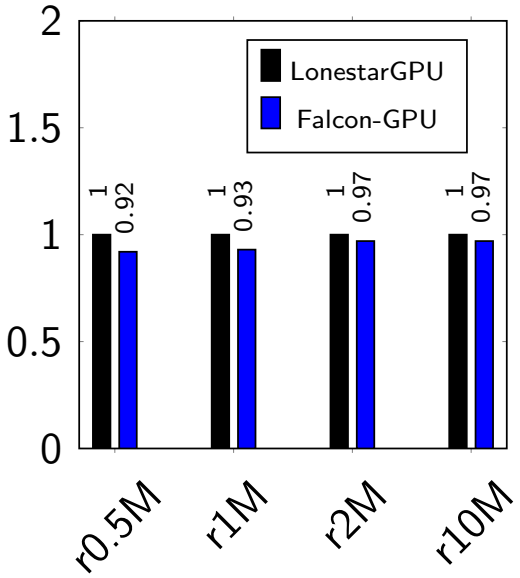
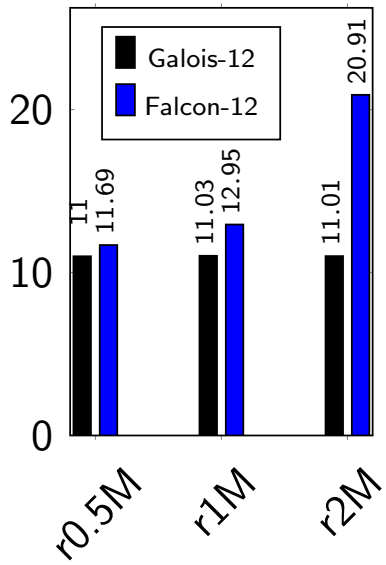
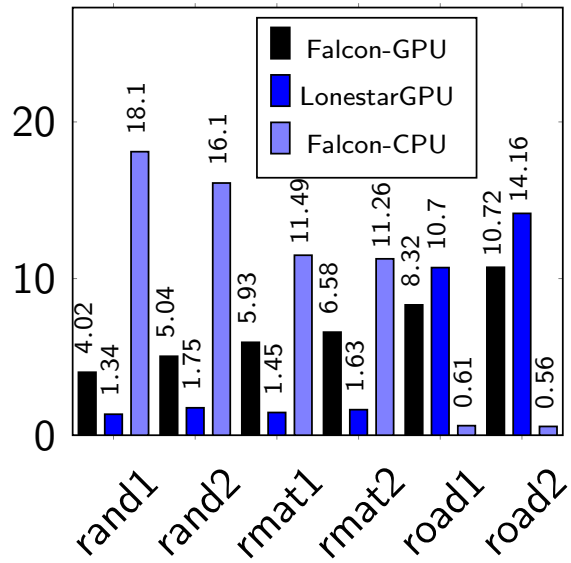


(a) DMR speedup over LonestarGPU

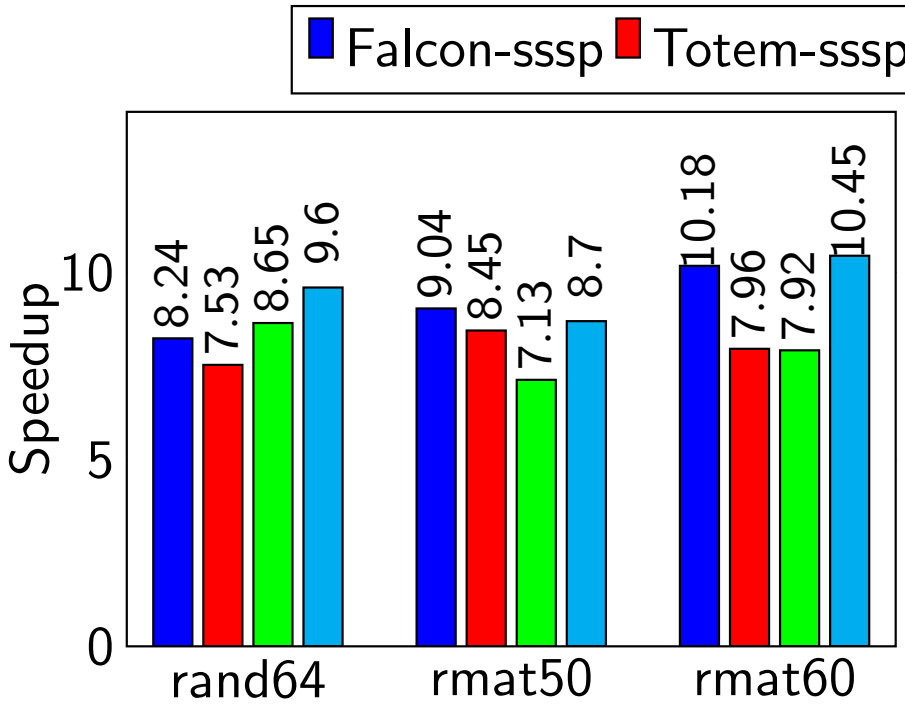


(b) DMR speedup over Galois single

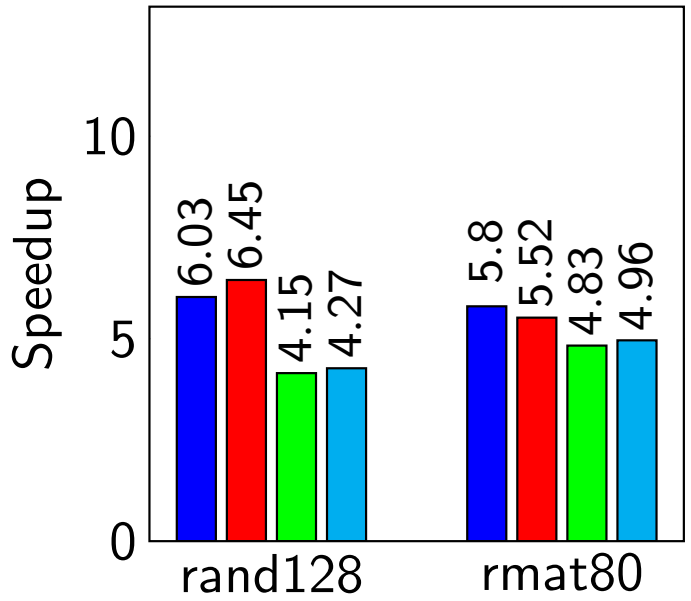


(c) Dynamic-SSSP- Self relative speedup

Morph Algorithm Results-Speedup
DMR(Delaunay Mesh Refinement) and Dynamic-SSSP



speedup on two GPUs



Speedup on two GPUs and one CPU

Heterogeneous Execution-SSSP and BFS speedup

Partitioned Execution of one Algorithm on Multiple Devices

```
1  fun1(Point ori, Point incom){
2        if(orig.dist >incom.dist)
3              orig.dist=incom.dist
4  }
5  relaxgraph(Point p, HGraph hgraph){
6     foreach(t in p.outnbrs)
7        MIN(t.dist,p.dist+hgraph.getWeight(p,t), hgraph.changed[0]);
8  }
9  main(int argc, char *argv[]) {
10       HGraph hgraph;
11       hgraph.addPointProperty(dist, int);
12             hgraph.addProperty(changed, int);
13       hgraph.read(argv[1]);
14             hgraph.makePartition(1,1,ORDERED);
15             hgraph.updateFunction(fun1);
16       foreach(t In hgraph.points) t.dist=1234567890;
17       hgraph.points[0].dist=0;
18       while( 1 ){
19            hgraph.changed[0]=0;
20            foreach(t In hgraph.points)relaxgraph(t,hgraph);
21            if(hgraph.changed[0]==0)break;
22            hgraph.updatePartition();
23       }
24       for(int i = 0;i <hgraph.npoints; i++)
25          printf("%d", hgraph.points[i].dist);
26 }
```

A SIMPLE EXAMPLE

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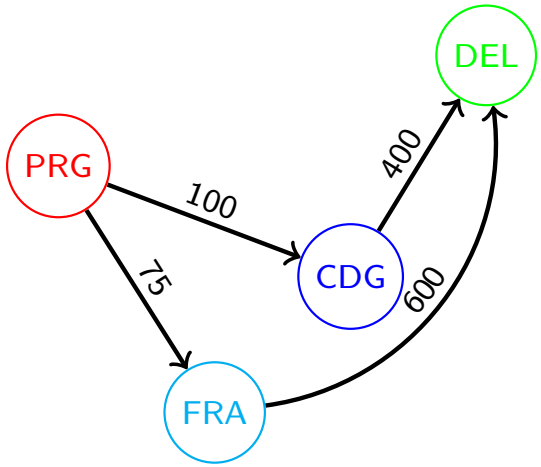

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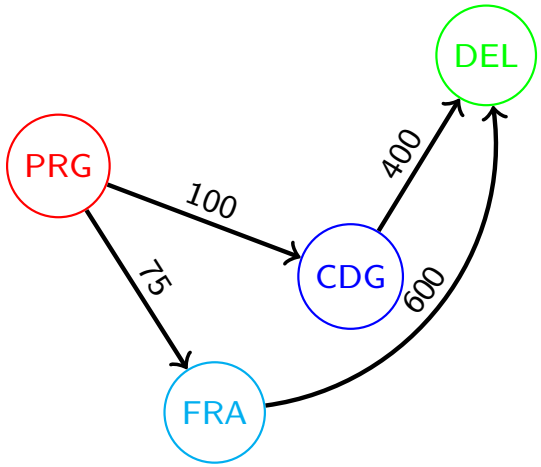

Part1(PRG, CDG)
0 , INF , INF , INF
0 , 100 , 75 , INF
0 , 100 , 75 , INF
0 , 100 , 75 , 500
0 , 100 , 75 , 500

Part2(FRA,DEL)
0 , INF, INF , INF
0 , INF , INF , INF
0 , 100 , 75 , INF
0 , 100, 75 , 675
0 , 100 , 75 , 500

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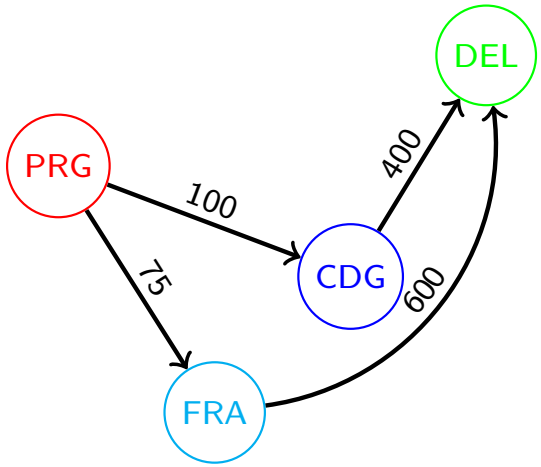

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0 , 100 , 75 , INF	0 , INF , INF , INF
0 , 100 , 75 , INF	0 , 100 , 75 , INF
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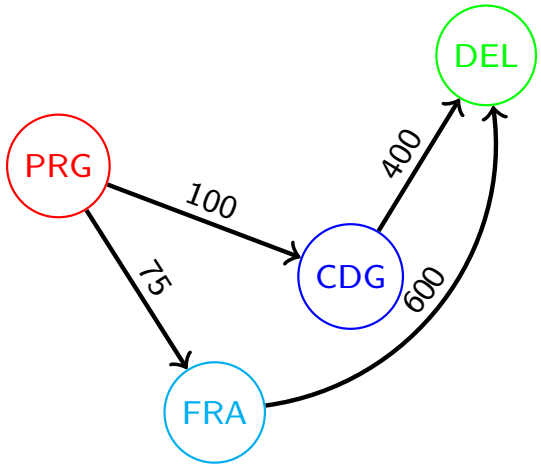

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   ii) Making DSL more simple(say removing <GPU>tag).
   iii) Support for non-Nvidia GPUs by providing OpenCL backend.
   iv) adding optimizations on Compiler.

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6. The Falcon compiler will made available online.

Questions??

THANK YOU

DĚKUJI

```
1  relaxgraph(Point <GPU>p, Graph <GPU>graph) {
2      foreach (t In p.outnbrs)
3        MIN(t.dist, p.dist + graph.getweight(p, t), changed);
4  }
```

```
1  #define t (((struct_hgraph *)(graph.extra)))
2  __global__ void relaxgraph(GGraph graph, int x) {
       id = blockIdx.x * blockDim.x +
3                threadIdx.x + x;
4      if (id <graph.npoints){
5      int falcft0 = graph.index[id];
6      int falcft1 = graph.index[id+1]-graph.index[id];
8      for (falcft2 = 0; falcft2 <falcft1; falcft2++) {
9          int ut0 = 2 * (falcft0 + falcft2); //edge index
10         int ut1 = graph.edges[ut0].ipe; //dest point
11         int ut2 = graph.edges[ut0 + 1].ipe;
12         GMIN(&t->dist[ut1], t->dist[id] + ut2, changed);
13     }
14 }
```

Code generated for GPU

```
1  relaxgraph(Point p, Graph graph) {
2      foreach (t In p.outnbrs)
3        MIN(t.dist, p.dist + graph.getweight(p, t),
       changed);
4  }
```

```
1  #define t (((struct_hgraph *)(graph.extra)))
2  relaxgraph(int &p ,HGraph &graph) {
3      int falcft0 = graph.index[p];
4      int falcft1 = graph.index[p+1]-graph.index[p];
7      for (int falcft2 = 0; falcft2 <falcft1;
       falcft2++) {
8          int ut0 = 2 * (falcft0 + falcft2);
9          int ut1 = graph.edges[ut0].ipe;
10         int ut2 = graph.edges[ut0 + 1].ipe;
               HMIN(&t->dist[ut1],
11         t->dist[p] + ut2, ut1, changed);
12     }
14 }
```

Code generated for CPU

Code generated for relaxgraph function of SSSP example

```
1  int <GPU>changed=0,lev=0;
2  BFS(Point <GPU>p,Graph <GPU>graph,int lev) {
3      foreach( t In p.outnbrs ){
4          if(t.dist>(lev+1)) {
5          t.dist=lev+1;changed=1;
6          }
7      }
8  }
9  main(int argc, char *name[]) {
10     Graph hgraph;
11     hgraph.addPointProperty(dist,int);
12     hgraph.read(name[1]);
13     hgraph.getType() <GPU>graph;
14     graph=hgraph;
15     foreach(t In graph.points)t.dist=1234567890;
16     graph.points[0].dist=0;
17     while( 1 ){
18         changed=0;
19         foreach(t In graph.points)(t.dist==lev)
           BFS(t,graph);
20         if(changed==0)break;
21         lev++;
22     }
23     for(int i=0;i<graph.npoints;i++)
24     printf("%d\n",graph.points[i].dist);
25 }
```

Falcon code for BFS on GPU

```
1  int changed=0,lev=0;
2  BFS(Point p,Graph graph,int lev) {
3      foreach( t In p.outnbrs ){
4          if(t.dist>(lev+1)) {
5          t.dist=lev+1;changed=1;
6          }
7      }
8  }
9  main(int argc, char *name[]) {
10     Graph hgraph;
11     hgraph.addPointProperty(dist,int);
12     hgraph.read(name[1]);
13     foreach(t In hgraph.points)
       t.dist=1234567890;
14     hgraph.points[0].dist=0;
15     while( 1 ){
16         changed=0;
17         foreach(t In hgraph.points)
           (t.dist==lev)BFS(t,hgraph,lev);
18         if(changed==0)break;
19         lev++;
20     }
21     for(int i=0;i<hgraph.npoints;i++)
22     printf("%d\n",hgraph.points[i].dist);
23 }
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Falcon code for BFS on CPU

Dynamic Graph algorithms

1. `Falcon` provides addPoint(),addEdge() function on Graph class.

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Dynamic Graph algorithms

1. `Falcon` provides addPoint(),addEdge() function on Graph class.
2. `Falcon` compiler checks for such function during code generation.
3. If such a function is found in DSL, Graph is pre-allocated with more space(say 3 times).
4. Deletion of Points/Edges are managed by marking. No Garbage Collection.

Graph member function addProperty() function

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4. This function can be used to view Graph as Collection of triangles(DMR) or as Collection of clauses(Survey Propagation).

Code for Parallel Execution of SSSP and BFS on two GPUs in Falcon

```
1  int <GPU>changed;
2  SSSPBFS(char *name) { //begin SSSPBFS
3  Graph hgraph;//Graph object on CPU
4  hgraph.addPointProperty(dist,int);
5  hgraph.addProperty(changed,int);
6  hgraph.getType() <GPU>graph0;//Graph on GPU0
7  hgraph.getType() <GPU>graph1;//Graph on GPU1
8  hgraph.addPointProperty(dist1,int);
9  hgraph.read(name);//read Graph from file to CPU
10 graph0=hgraph;//copy entire Graph to GPU0
11 graph1=hgraph;//copy entire Graph to GPU1
12 foreach(t In graph0.points)t.dist=1234567890;
13 foreach(t In graph1.points)t.dist=1234567890;
14 graph0.points[0].dist=0;
```

```
16 parallel sections { //do in parallel
17   section {//compute BFS on GPU1
18     while(1){
19       graph1.changed[0]=0;
20       foreach(t In graph1.points)BFS(t,graph1);
21       if(graph1.changed[0]==0) break;
22     }
23   }
24   section {//compute SSSP on GPU0
25     while(1){
26       graph0.changed[0]=0;
27       foreach(t In graph0.points)SSSP(t,graph0);
28       if(graph0.changed[0]==0) break;
29     }
30   }
31 }//end SSSPBFS
32 }
```