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Low-Power, Fault-Resilient Communications in a Million-Core Neural Processing Architecture

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Talk outline

- SpiNNaker Architecture
- Spiking neural networks
- Analysis of the interconnect
  - Multicast route generation
  - Stability under failures
  - Congestion sensitivity
  - Resilient to burstiness
- Conclusions

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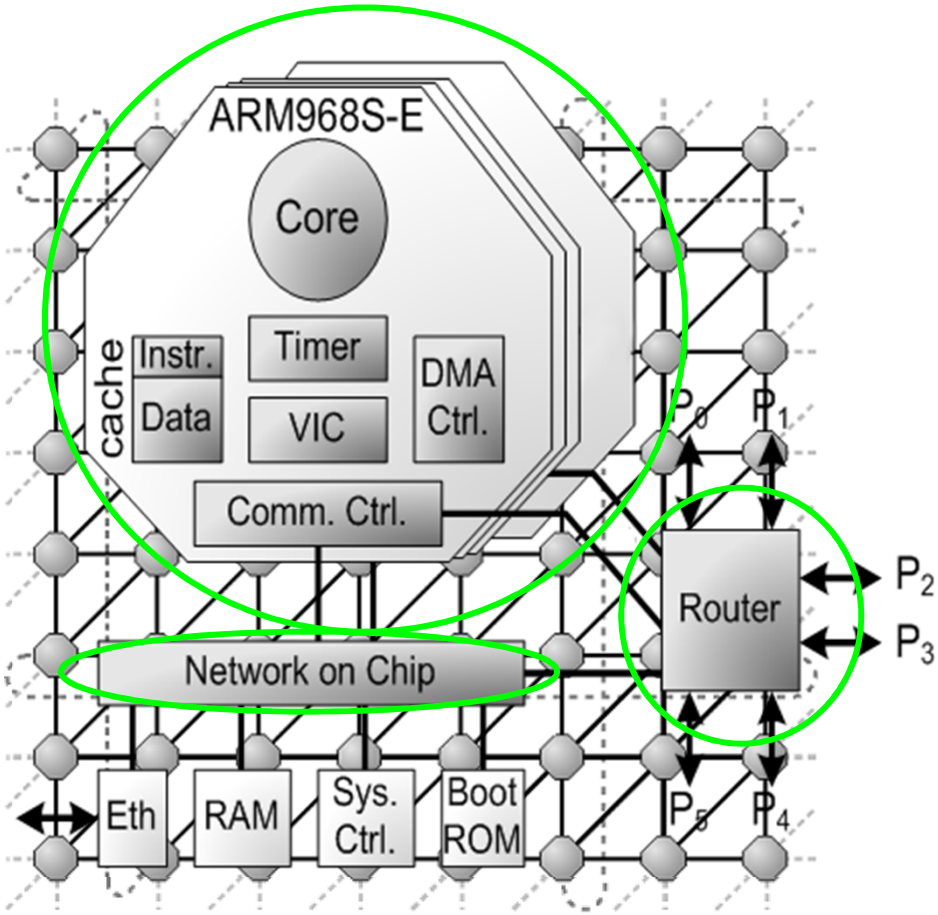
Overview of SpiNNaker

- Biologically-inspired massively parallel architecture
  - Up to 64K custom-made SoC chips
  - Over 1 million processors
- Simulation of very large-scale spiking neural networks in biological real-time
  - 10^9 neurons (~1% of the human brain)
  - 10^{12} synapses
- Communication-intensive application
  - Neuron activations are communicated to 1000s of other neurons
  - Up to 10^{13} communication events per second

Best architecture for supporting such a communication-demanding application ???

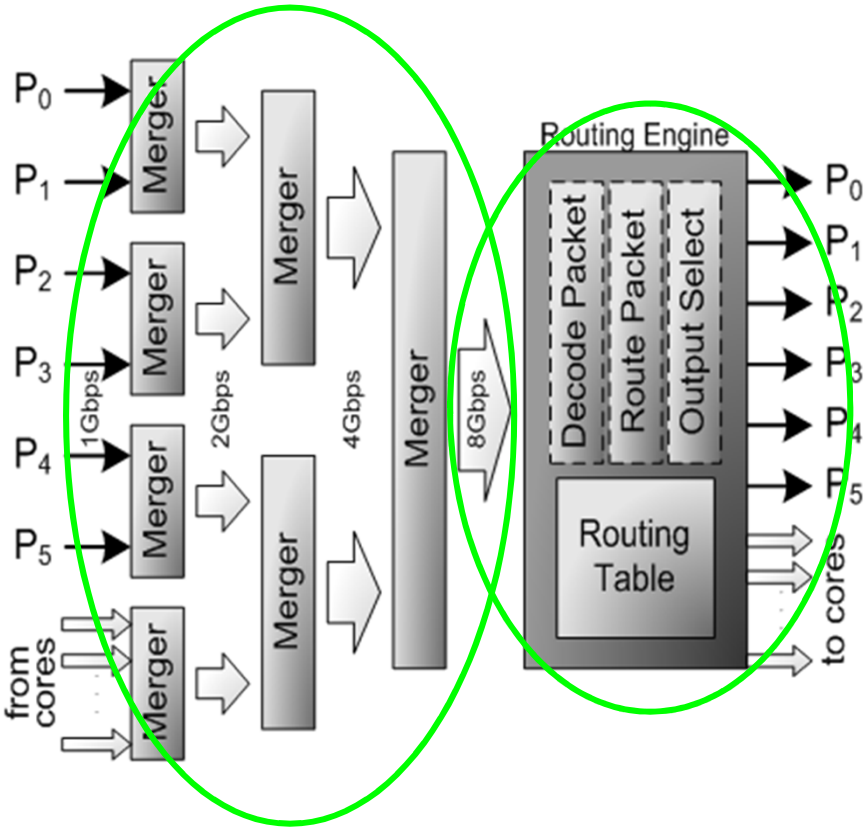
SpiNNaker architecture

- 18 extremely low power ARM cores
  - Up to 1000 neurons/core
  - ~1Watt per chip
- Asynchronous NoC
  - Connects chip resources
- Router-centric design
  - All packets pass through the router
  - Router accessed via the NoC
- Triangular torus topology
  - Tradeoff between redundancy, performance and scalability



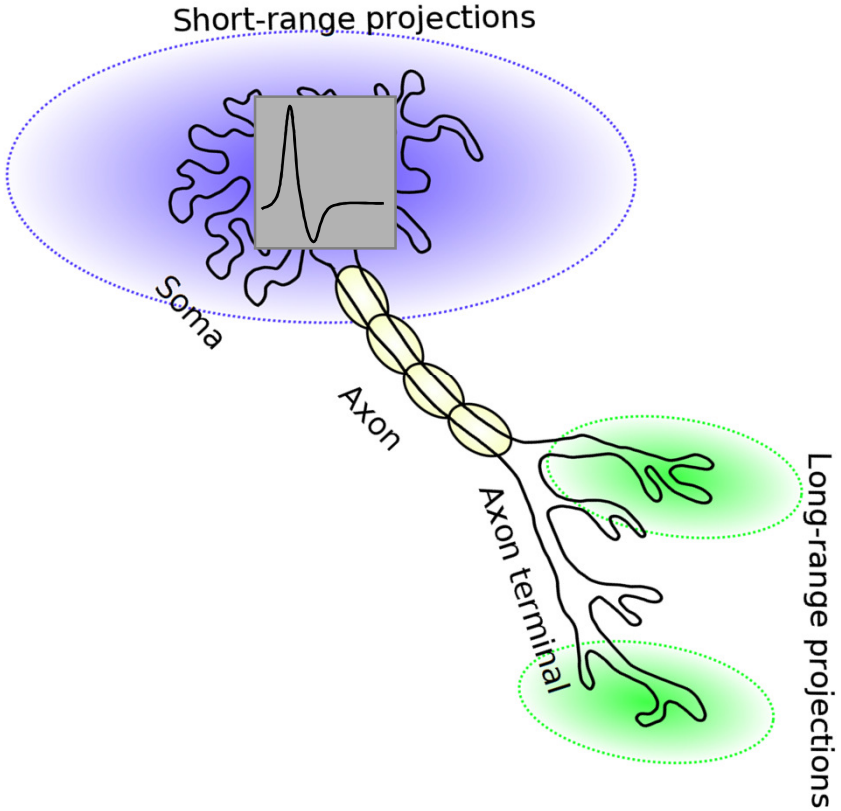
Router Architecture

- Hierarchical design
  - 3-stage port merging
    - Bandwidth doubled each stage
  - Packets use the routing engine once at a time
    - Router ~30x faster than links
    - Not expected to become the bottleneck
- Routing engine
  - Native Multicast
  - Associative routing tables (Source-based routing)
  - Built-in Emergency routing mechanism to exploit topological redundancy



Application Model

- PyNN is used to define neural nets
  - Highly integrated frontend
- Neurons stimulated beyond a threshold communicate through spike events
  - Biological neuronal nets favour local connectivity
  - These spikes need to be delivered to large sets of destinations (~1000)
  - Neuron multiplexing and multicast interconnects make this problem approachable
- How to deal with this high fan-out?



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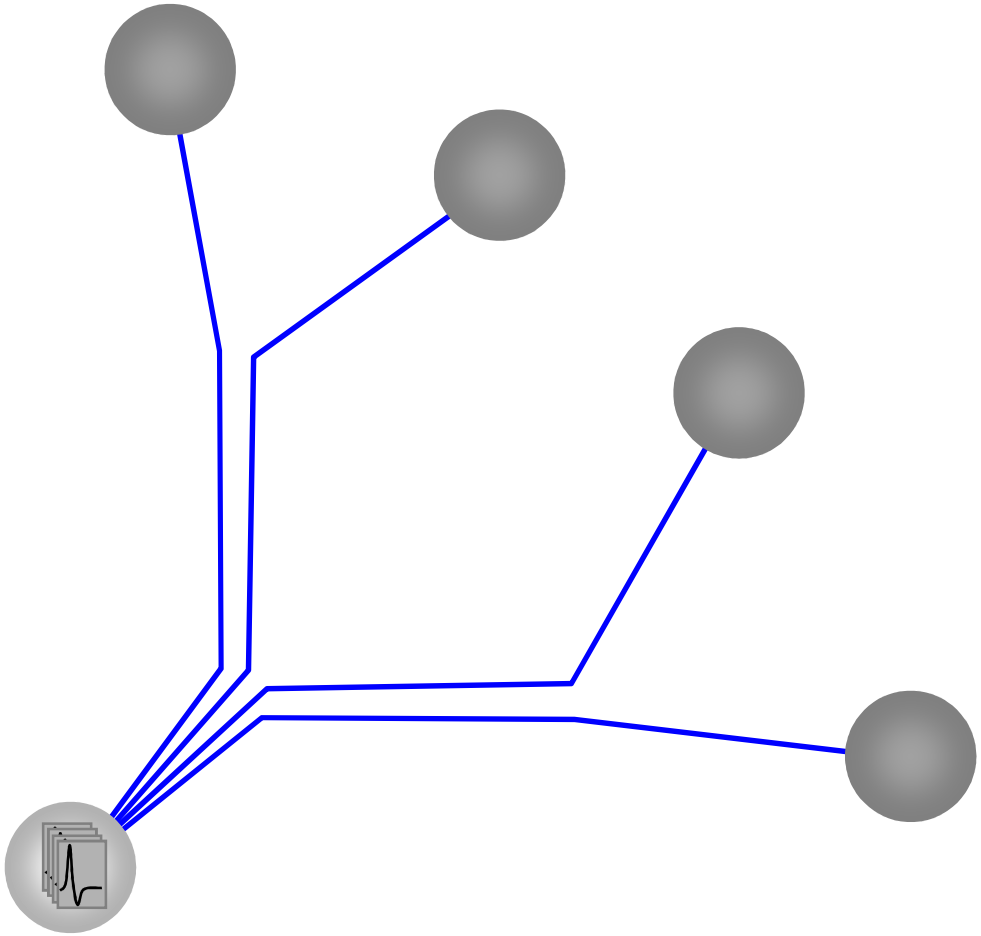
Unicast Delivery



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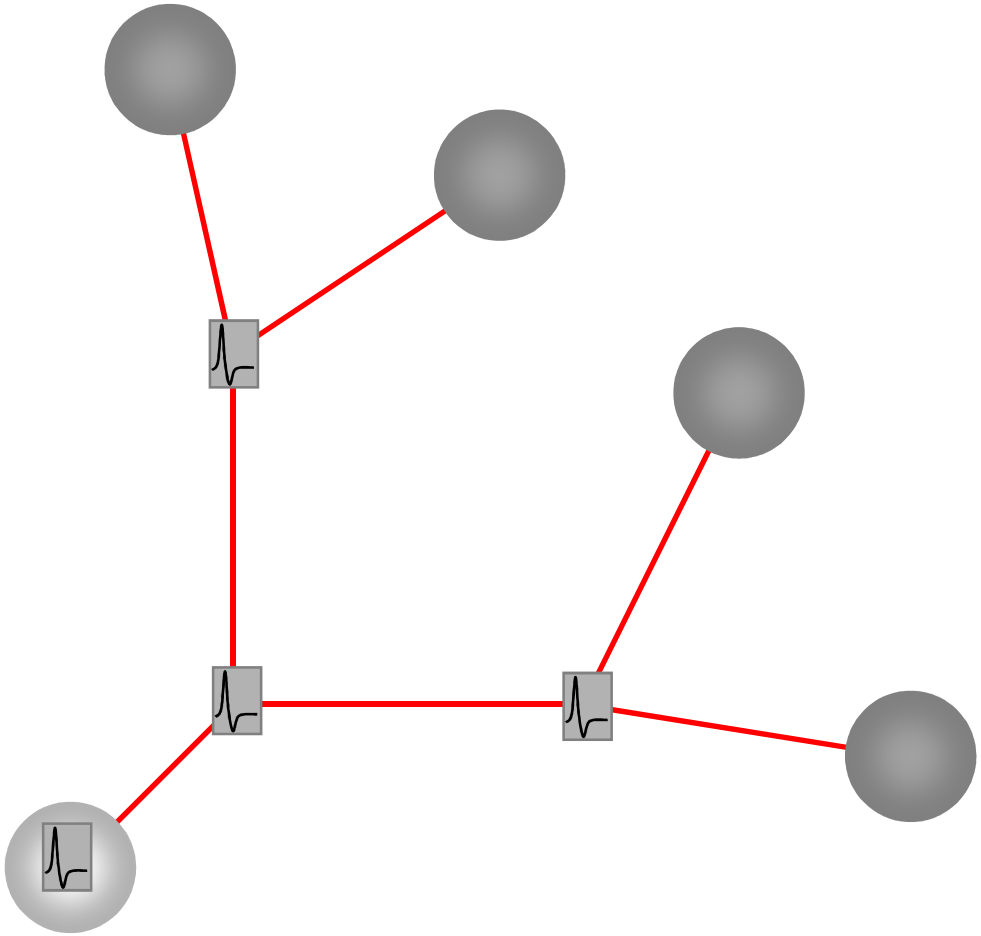
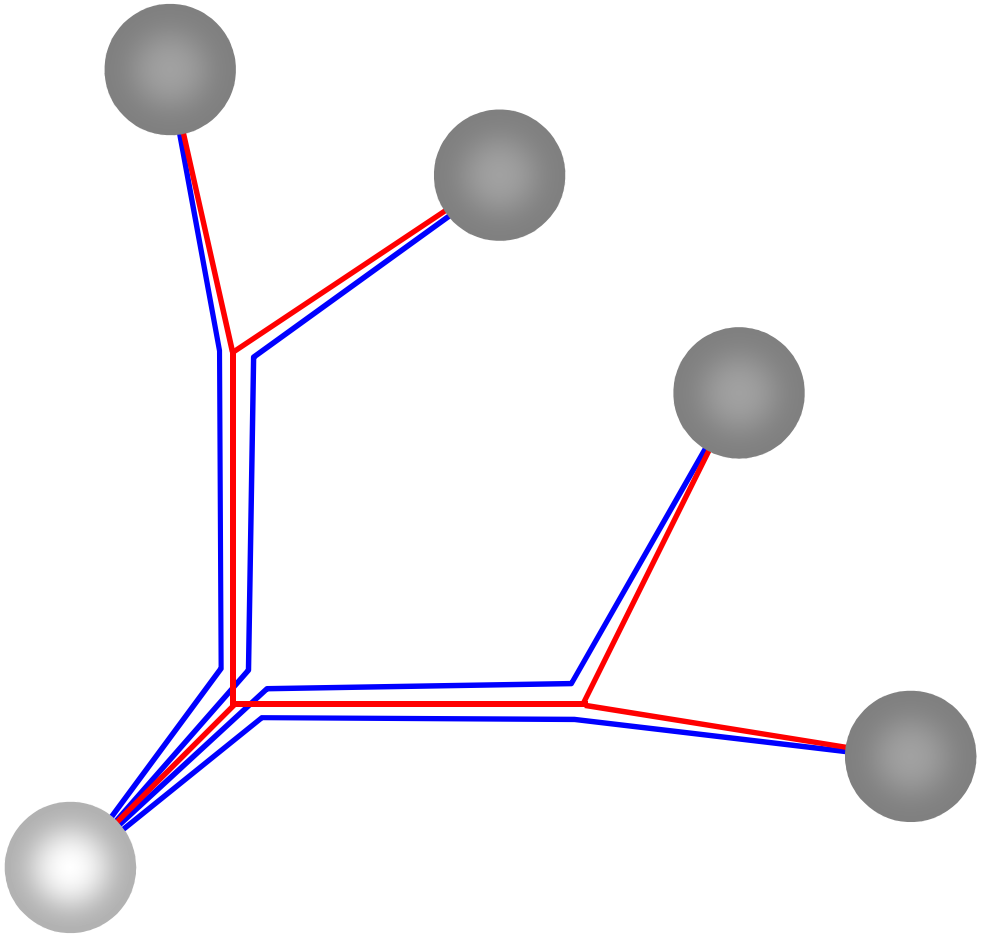
Multicast Delivery



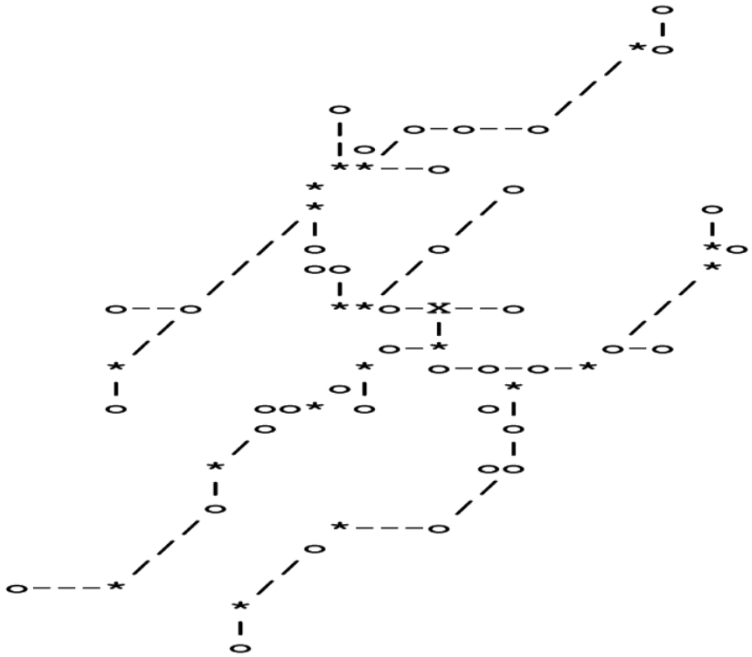
Unicast *vs* Multicast



- Multicast is more efficient
  - Avoids saturating links near the source
  - The overall bandwidth consumed is much lower
    - (7 vs 12 in this simple example, but unicast does not scale well)
- Generating multicast routes is far from trivial
  - We explored strategies for generate these routes

Multicast Routing Strategies

- Simple Oblivious Shortest Path Strategies
  - Dimension Order Routing
    - Baseline strategy, commonly used
    - Traverse the dimensions in a given order (XYD, in our case)
  - Longest Dimension First Routing
    - Traverse the dimension with more hops, then the other
- Smart Exploration Strategies
  - Enhanced Shortest Path Routing
    - Adapts routes only within the shortest path
  - Neighbourhood Exploring Routing
    - Explores in all direction and not restricted to shortest paths



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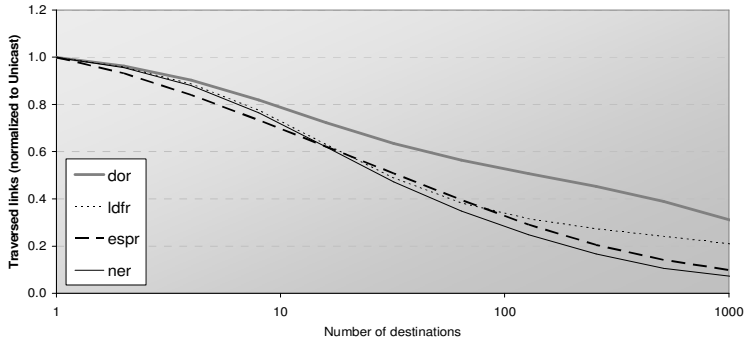
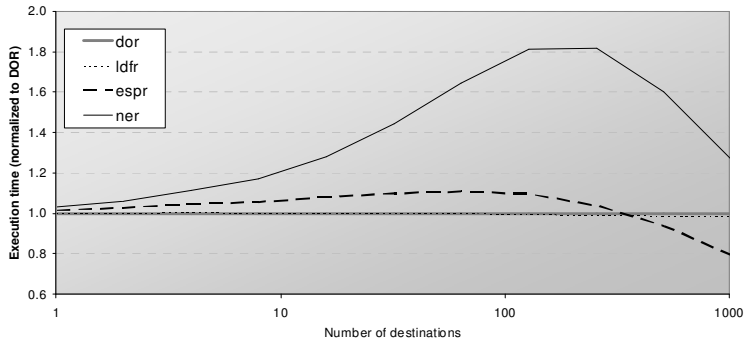
Multicast Routing Strategies

- Multicast is better suited for large-scale simulation of neural nets than unicast
  - Up to 10x less network bandwidth needed
- We proposed a well balanced collection of multicast route generation strategies
  - NER can be used to reduce network bandwidth
  - LDFR can be used to generate routes faster
  - ESPR offers a tradeoff between the two
  - DOR, the first strategy used by most groups in the community is not very well suited for multicast routing
  - Work on adapting them for fault-tolerance





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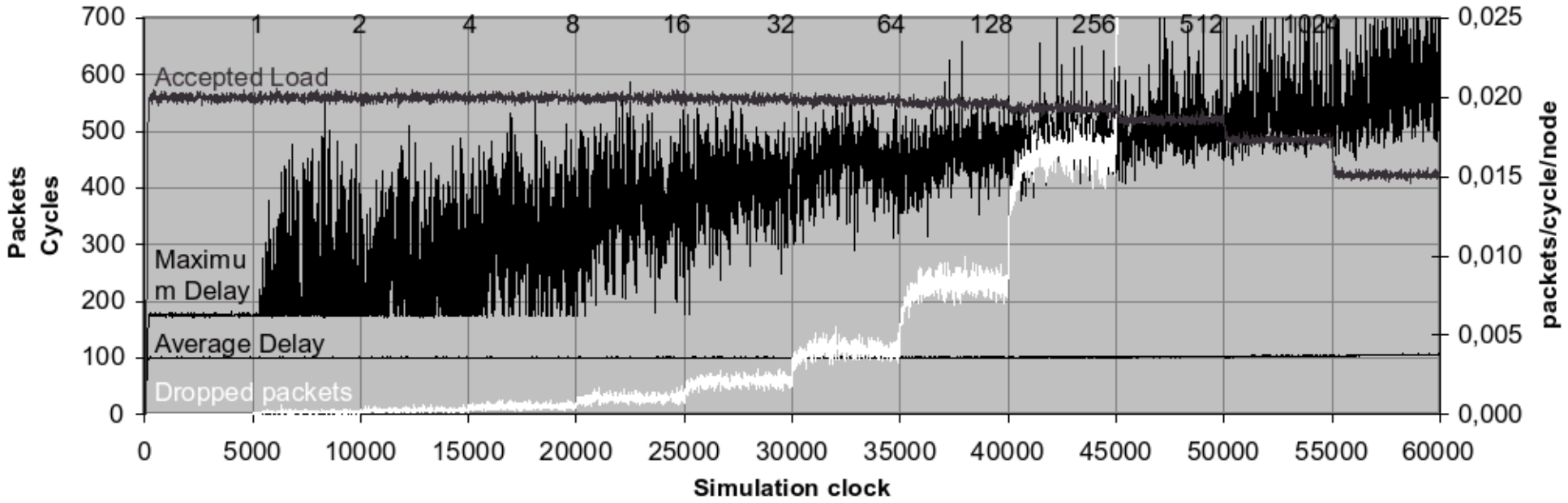
System Stability under Failures

*Emergency Routing **NOT** Activated*

- Very unstable behavior
  - Maximum delay heavily fluctuates
  - Dropped packets grows linearly with failures
  - Accepted load drops



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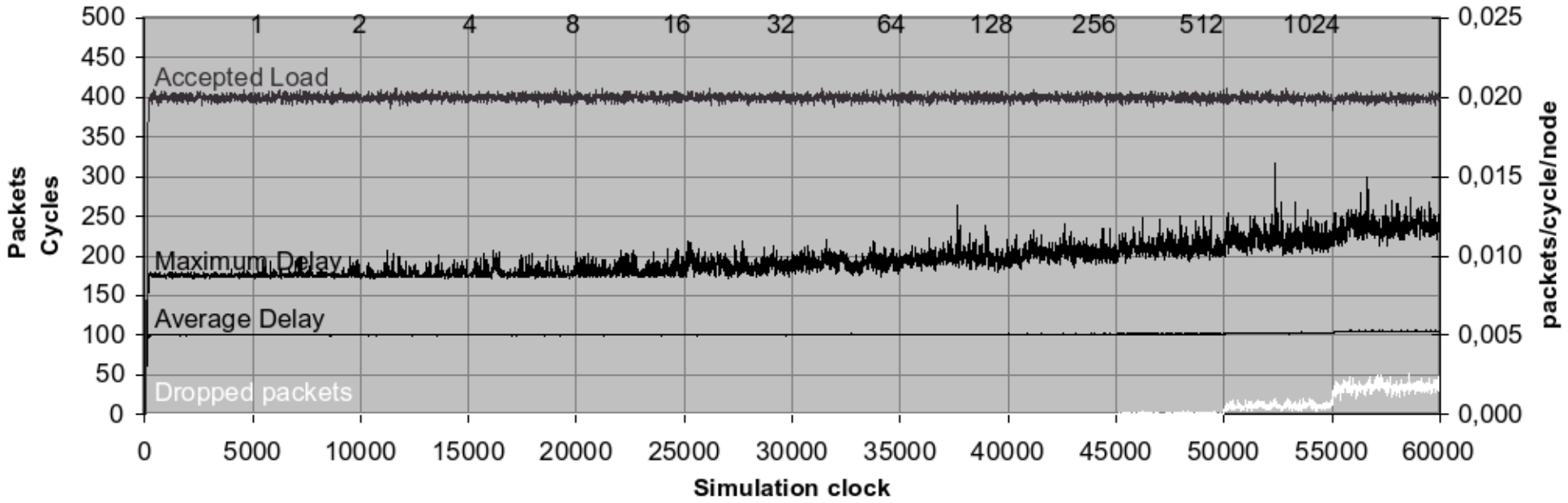
System Stability under Failures

Emergency Routing Activated

- Quite stable behavior
  - Maximum delay experiences slightly varies
  - Packets dropped remain 0 until 128 failures
- Shows Emergency routing suitability



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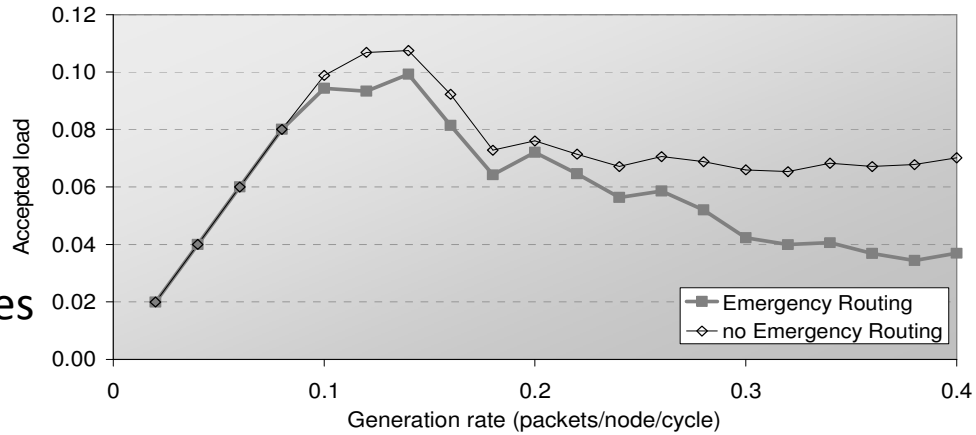
Effects of network congestion

- Emergency routing is known to be highly sensitive to congestion
  - Throughput before saturation (typical scenario) is not affected
  - Throughput beyond saturation is significantly reduced (up to 50%)
  - Emergency routed packets create more pressure in the reroute path, which exacerbates congestion issues



- Dynamic activation of Emergency routing when failures are detected
  - Avoids issues with transient congestion
  - Benefits from higher stability when failures in the network

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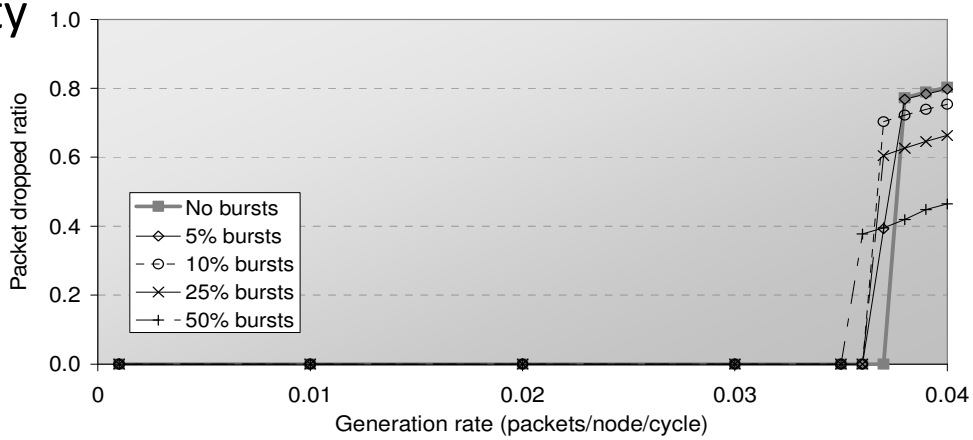
Effects of traffic Burstiness

- SpiNNaker's execution model exhibits bursty communication
- We analysed the interconnect ability to deal with such traffic model
  - Increasing the occurrence of long bursts barely affects the behaviour of the network
  - Network saturation point is slightly reduced (by ~5% for 50% bursts)
- In general the network behaves in a stable manner regardless of traffic burstiness



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Conclusions

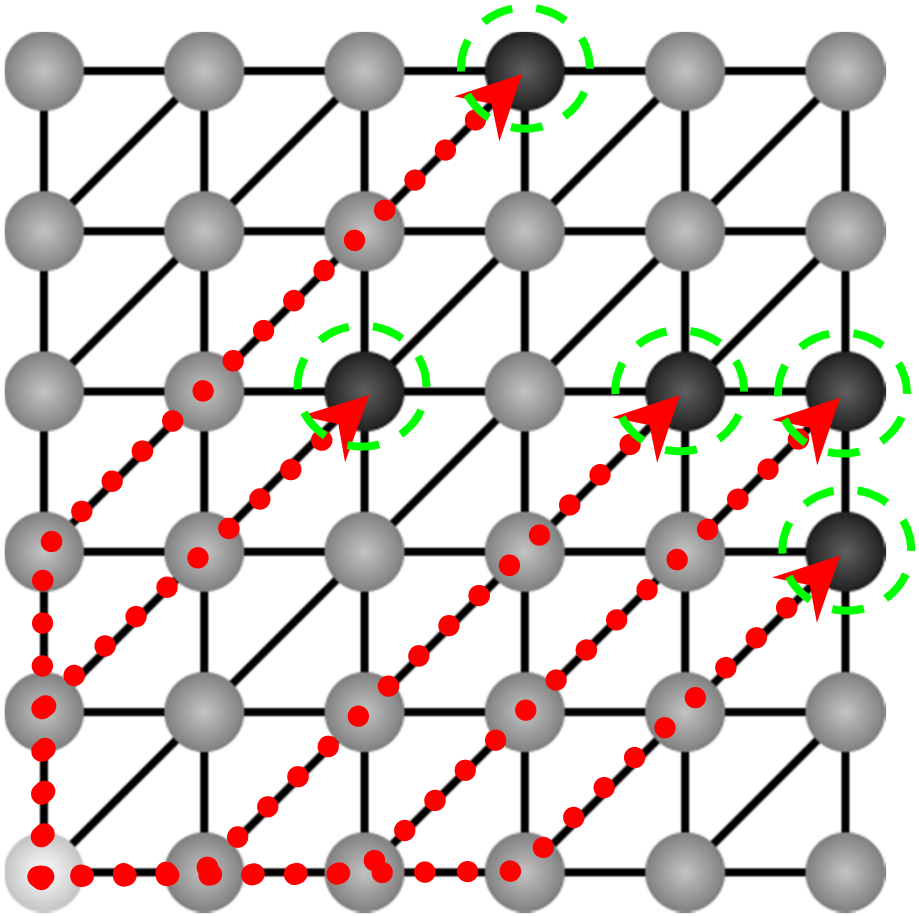
- Discussed SpiNNaker's most important features and strengths
  - Chip and interconnect architecture
  - Application Model
  - Full-fledged system construction progress
- SpiNNaker's low-spec, custom-made multicast router can sustain the communication-demanding neural applications
  - Stable in most foreseeable situations as regards traffic load, burstiness and network failures
  - Only in extreme scenarios of low locality may the network become a bottleneck
  - Multicast engine reduces network pressure
  - Provided a well-balanced collection of routing algorithms

Thanks for your attention

Questions

Extra slides

Dimension Order Routing



Lots of parallel branches – not very efficient

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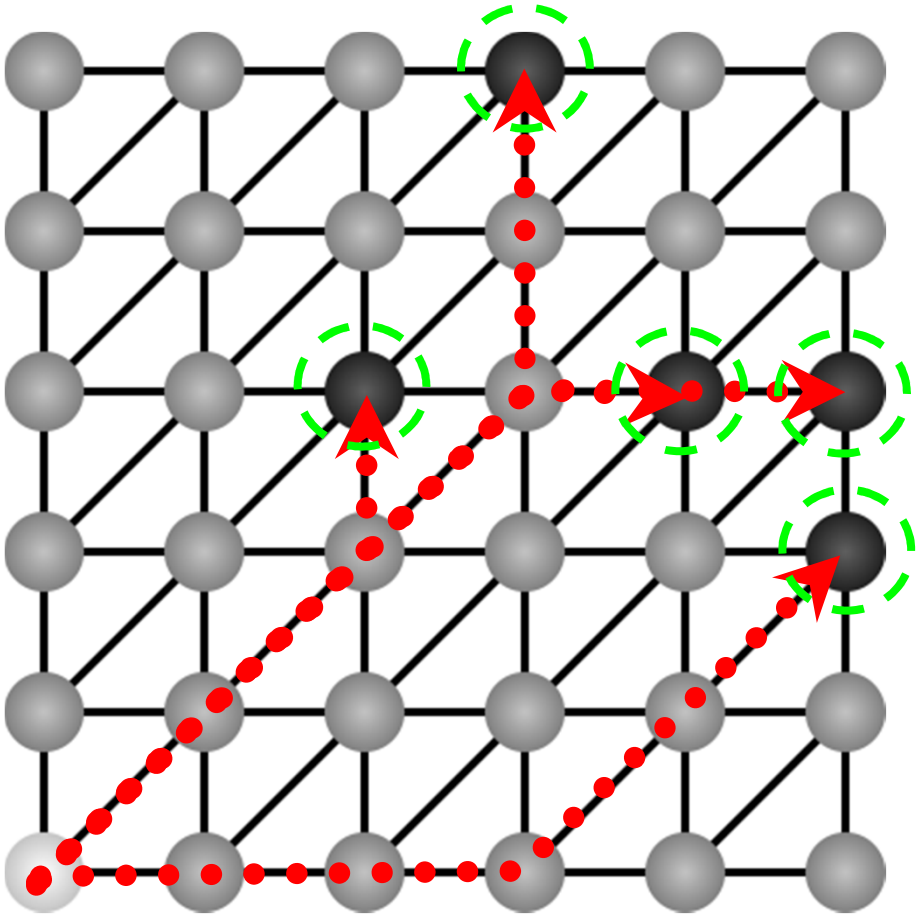
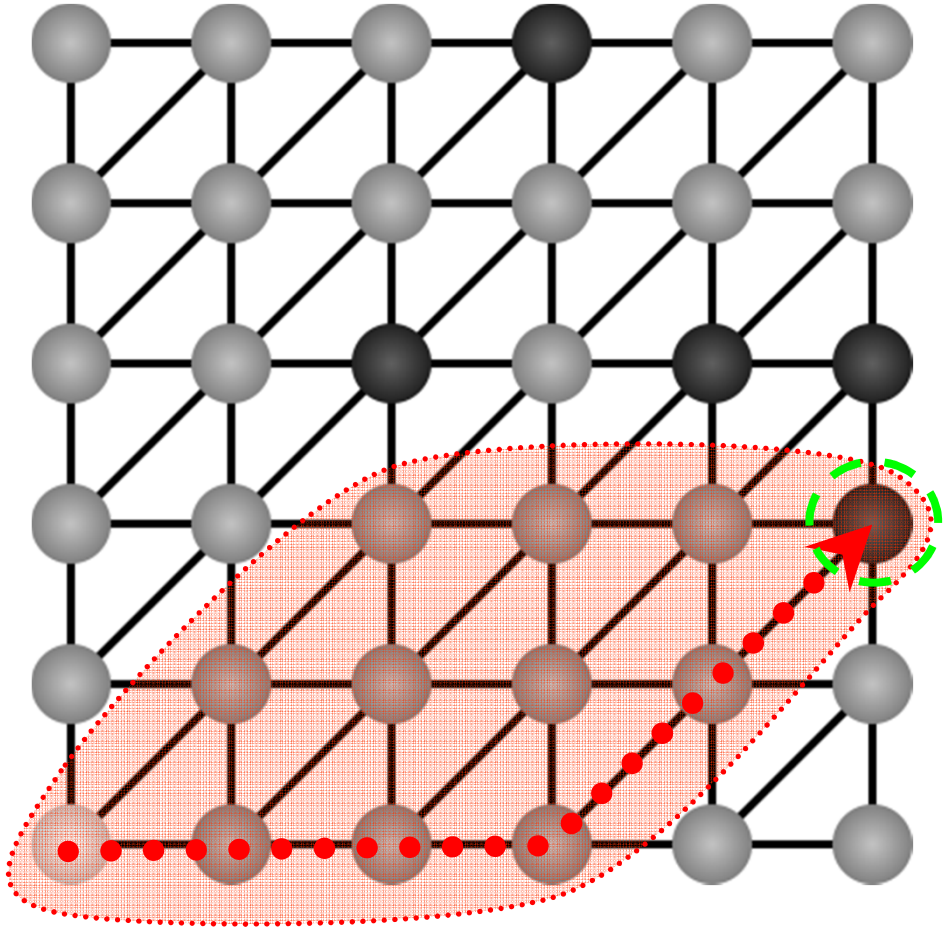
Longest Dimension First Routing



Main diagonal reused often

Enhanced Shortest Path Routing



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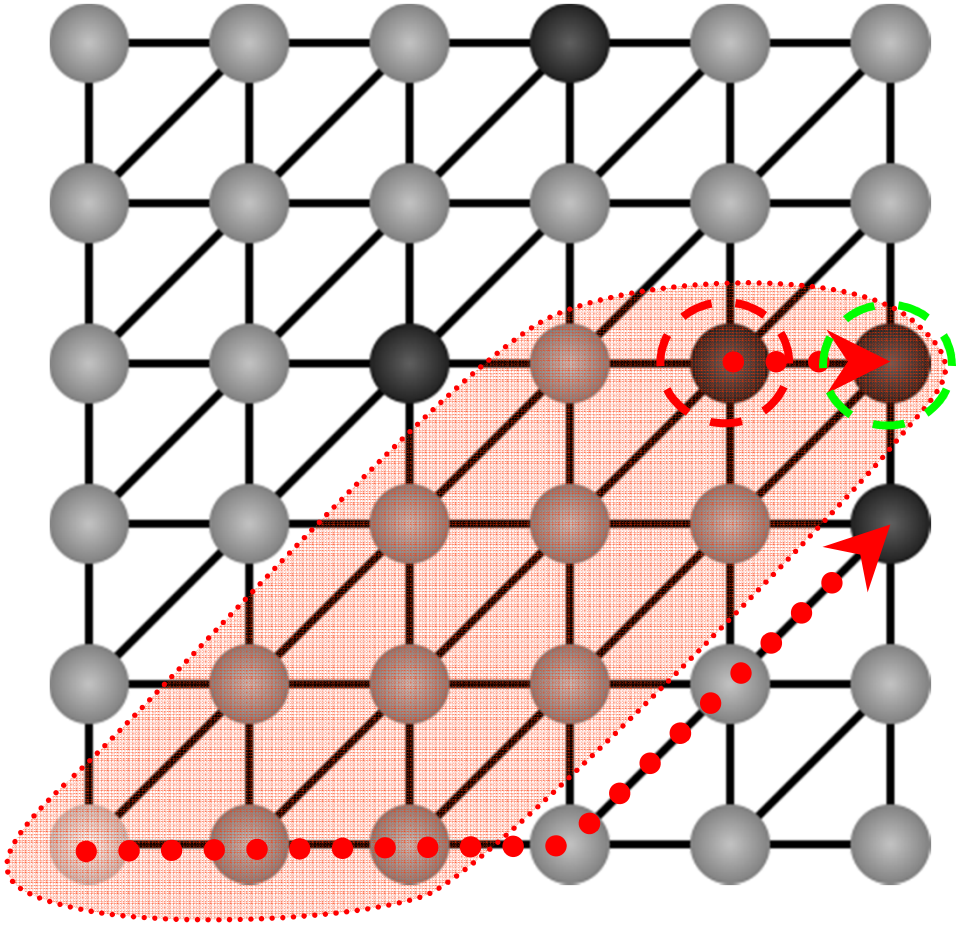
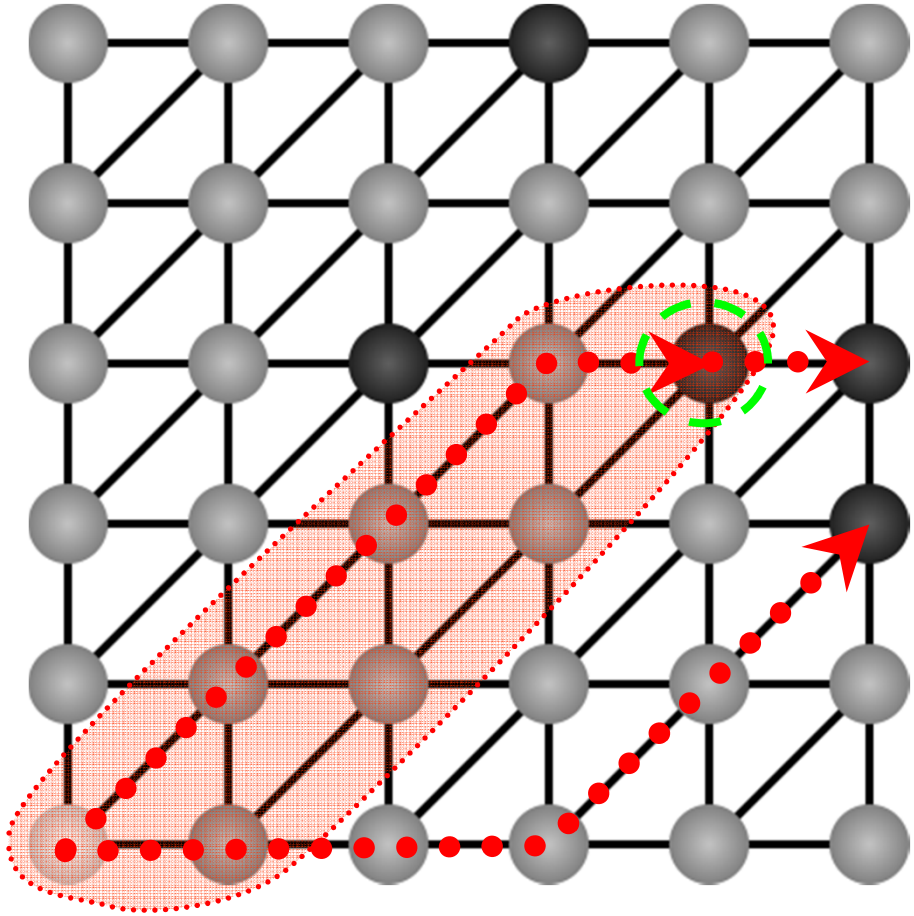
Enhanced Shortest Path Routing



Enhanced Shortest Path Routing



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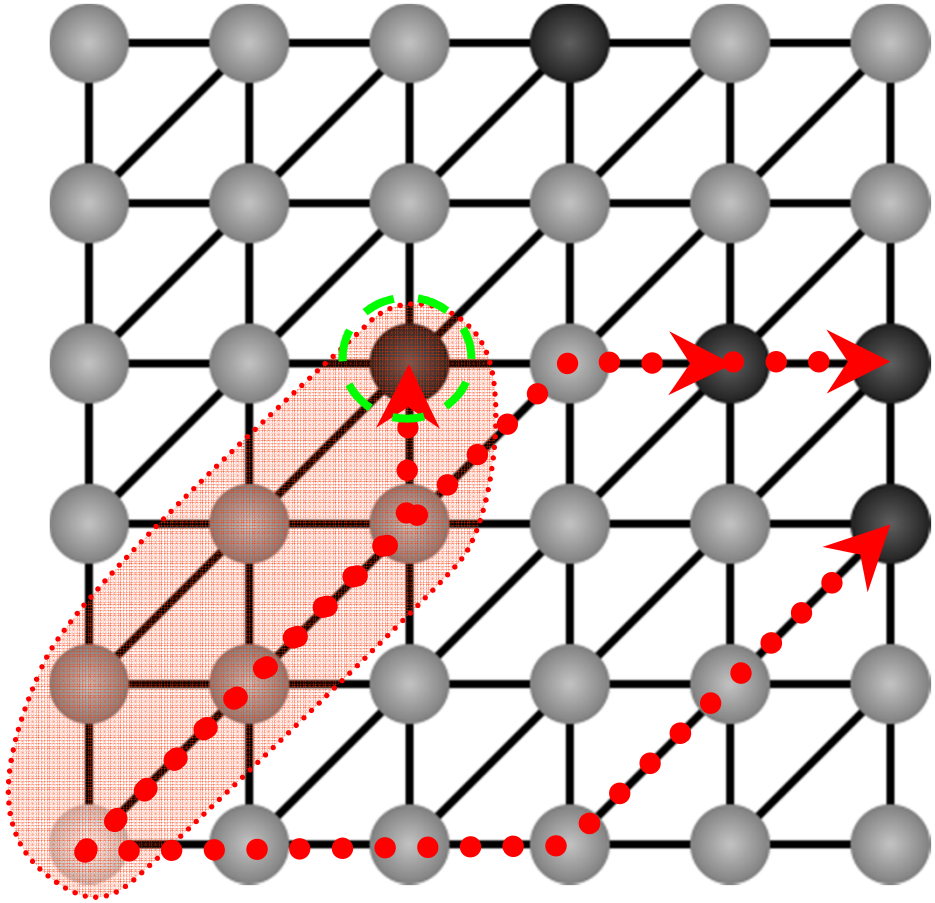
Enhanced Shortest Path Routing



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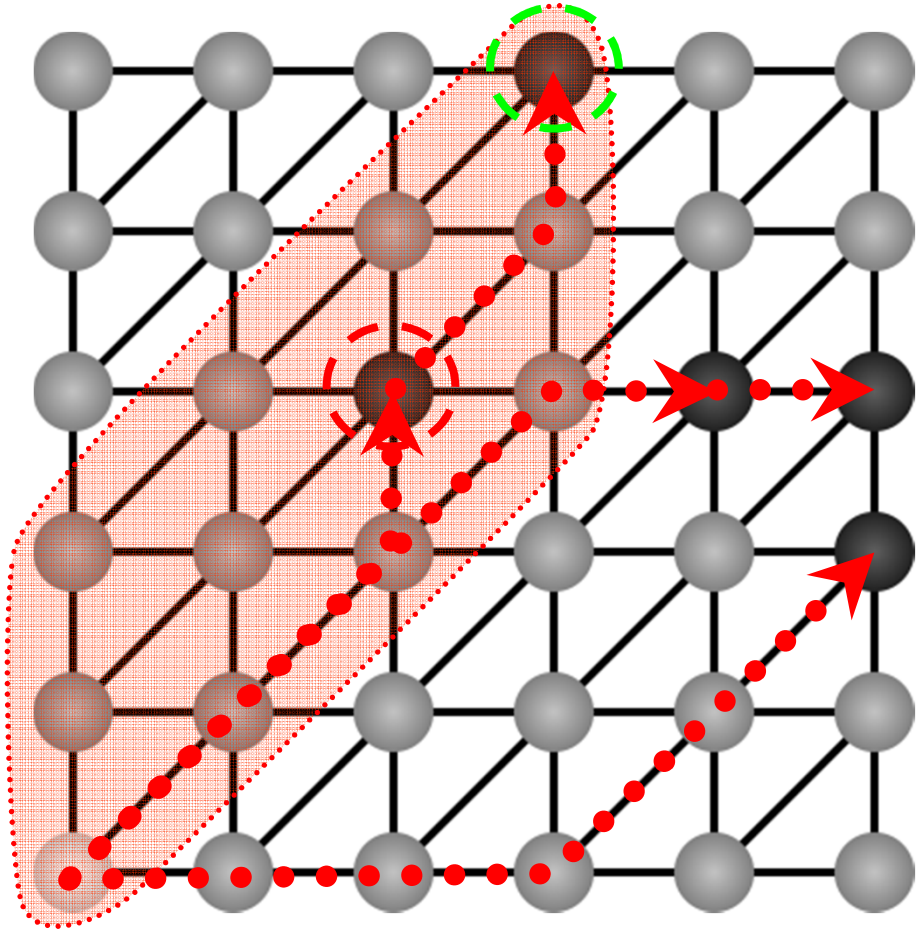
Enhanced Shortest Path Routing



Each node looks for the best connection in the shortest path

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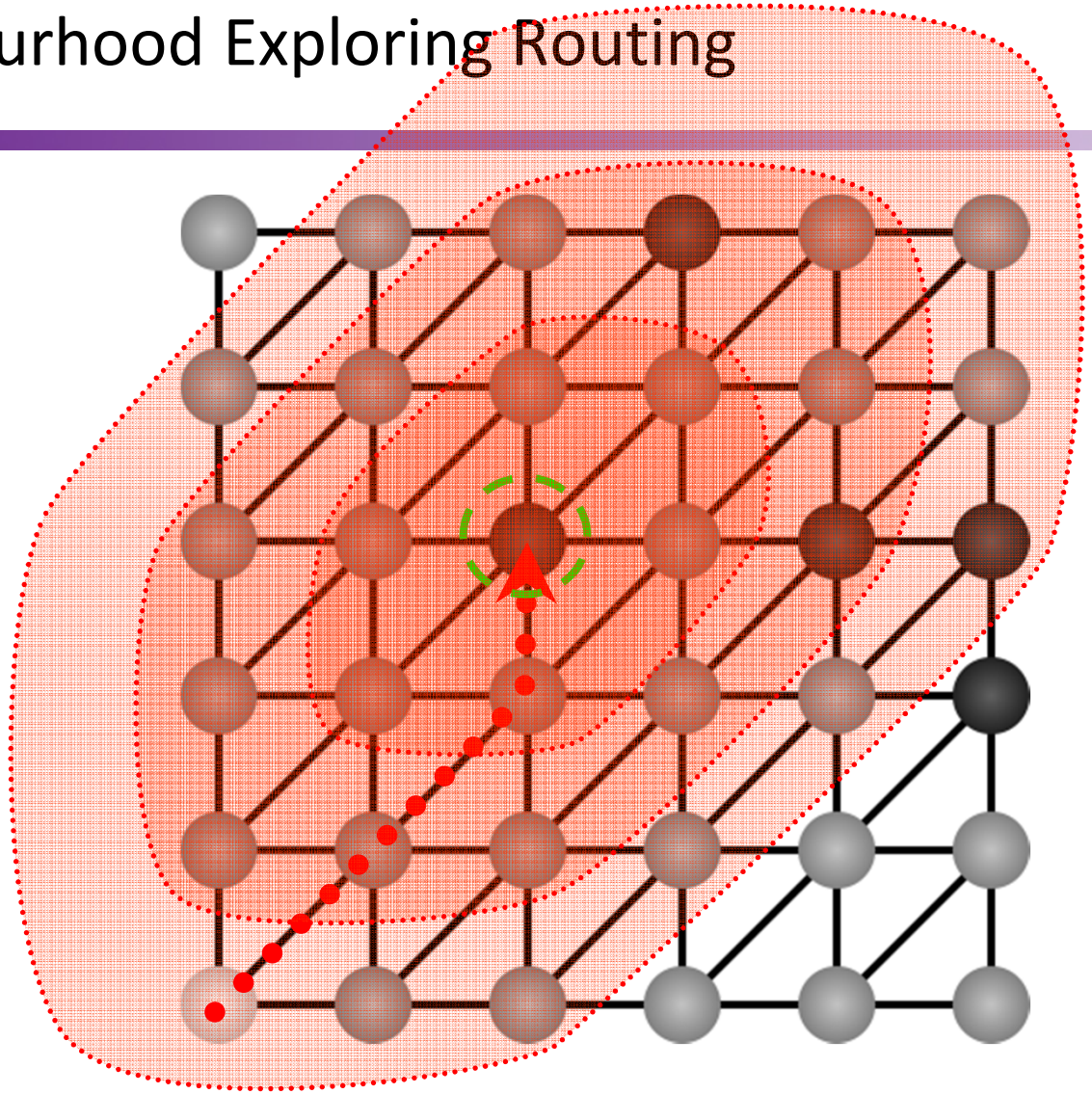
Neighbourhood Exploring Routing



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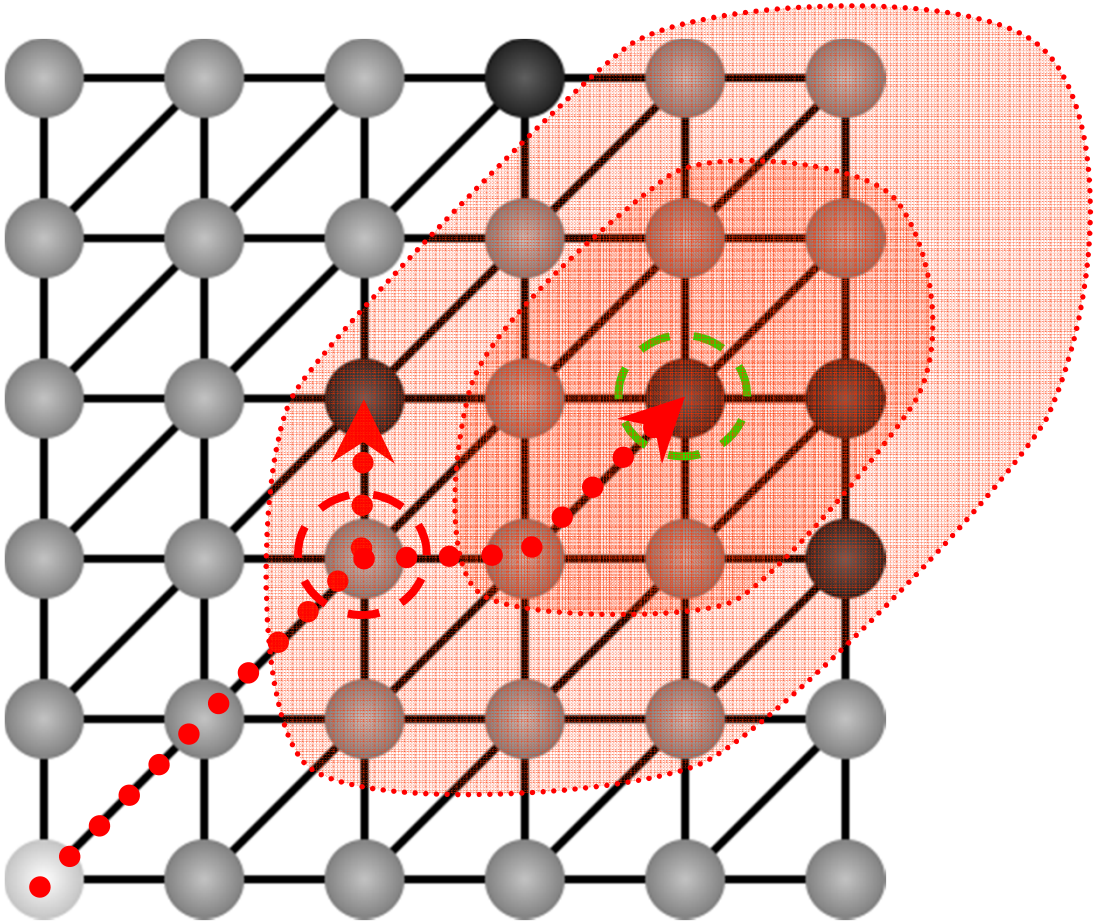

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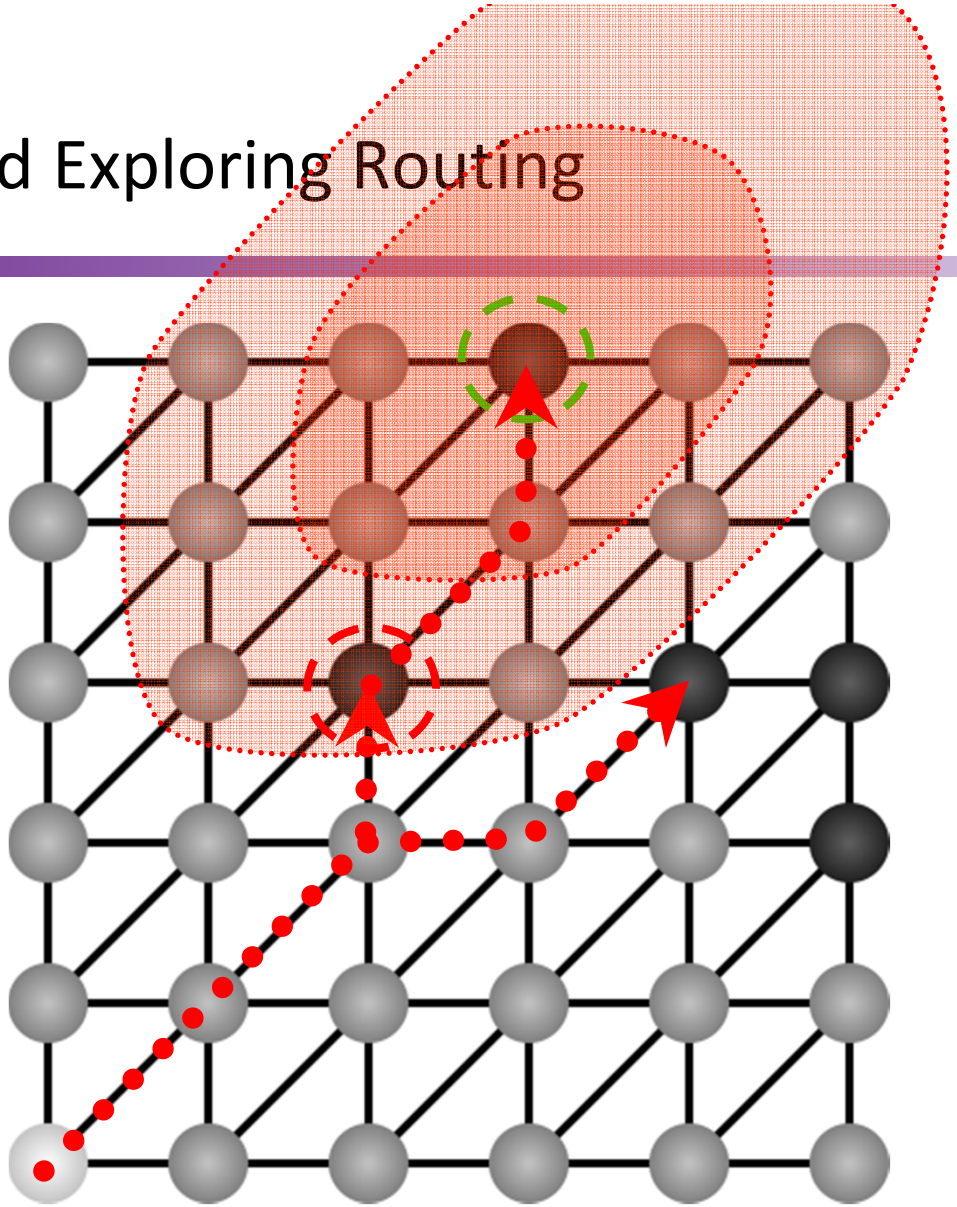

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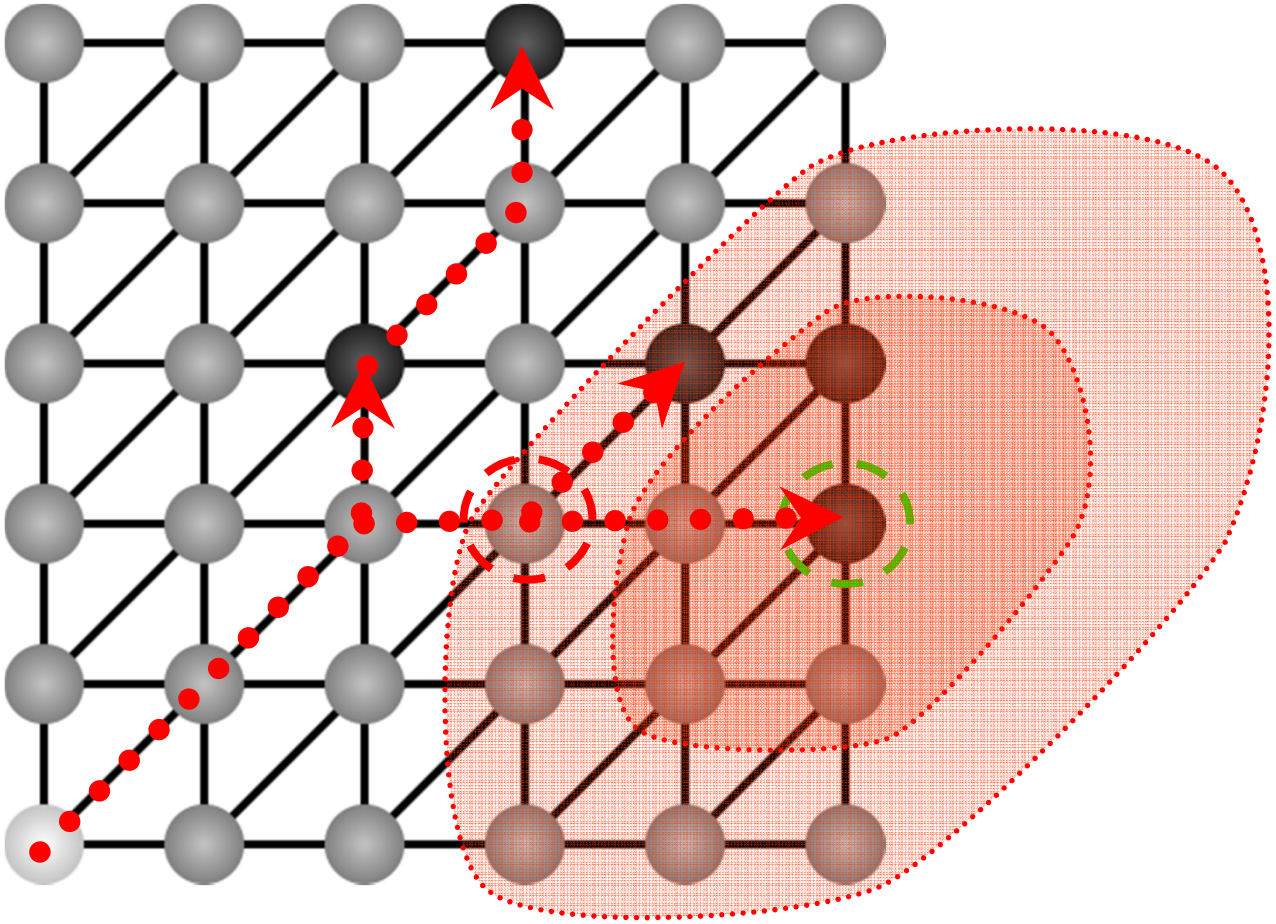

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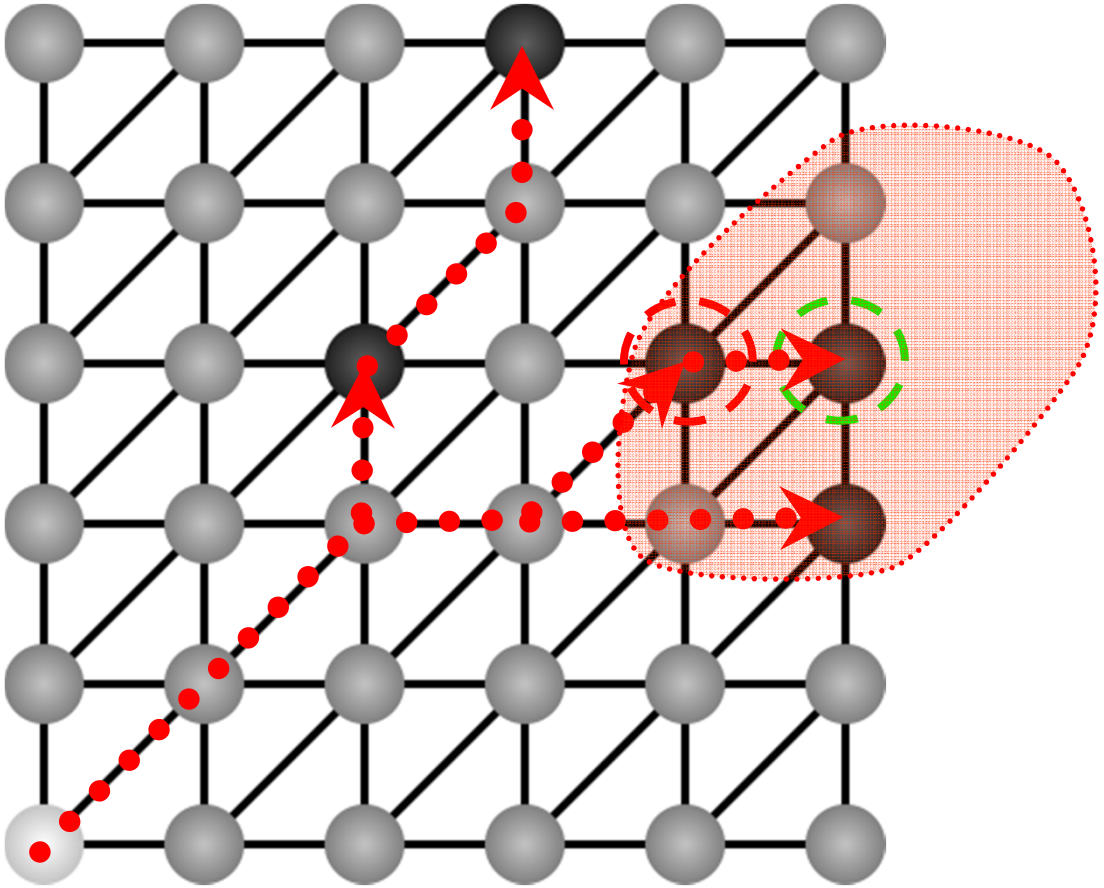
Neighbourhood Exploring Routing



Each node looks for the best connection around.

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SpiNNaker
a universal Spiking Neural Network architecture

Experimental Set-up

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SpiNNaker Architecture

- Essential info to motivate the performed analyses
  - Multicast routes are constructed before starting the neural application
    - Slower generation means larger waiting time before execution.

    Analyse route generation times
  - Limited Link Bandwidth
    - ~250 MB/s, need to reduce used bandwidth

    Assess bandwidth utilization and load balancing
  - Reduced number of routing table entries
    - 1024 masked entries per router, cannot exceed this number

    Measure routing table utilization
  - 18 cores per chip, of which 16 are typically used for the application
    - ~1000 neurons can be simulated per core
    - We need to avoid the network becoming the bottleneck

    Calculate number of supported neurons per core

How can we add fault tolerance?

Work in Progress

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FT techniques

- Want to avoid backtracking to reduce memory footprint
  - Greedy techniques implemented (under study yet)
    - Build the route one step at a time and react to failures locally
    - Based on the previously discussed algorithms
- Need to exploit the rich connectivity of the topology
  - …but need to ensure livelock free
    - Hence we should restrict to somehow limited routes
    - Mostly shortest routes
- Previous performance metrics still apply
  - Fast route generation
  - Reduced bandwidth utilization
  - Reduced routing table utilization

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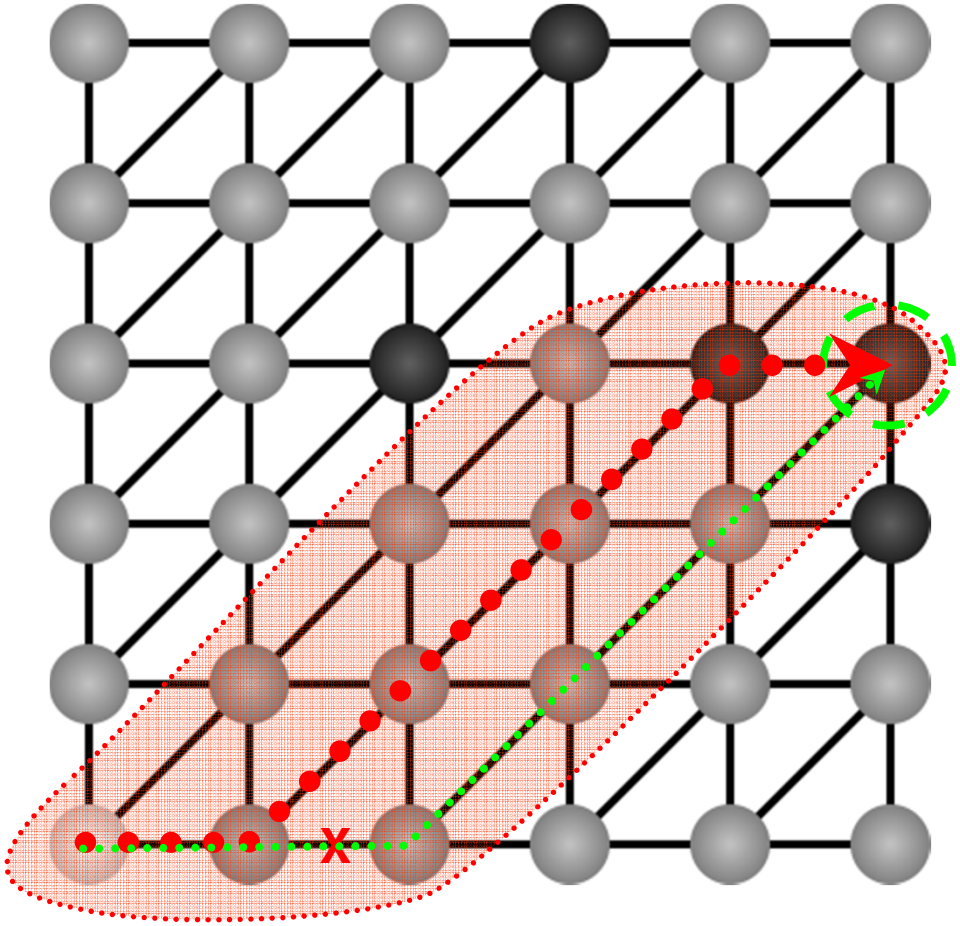
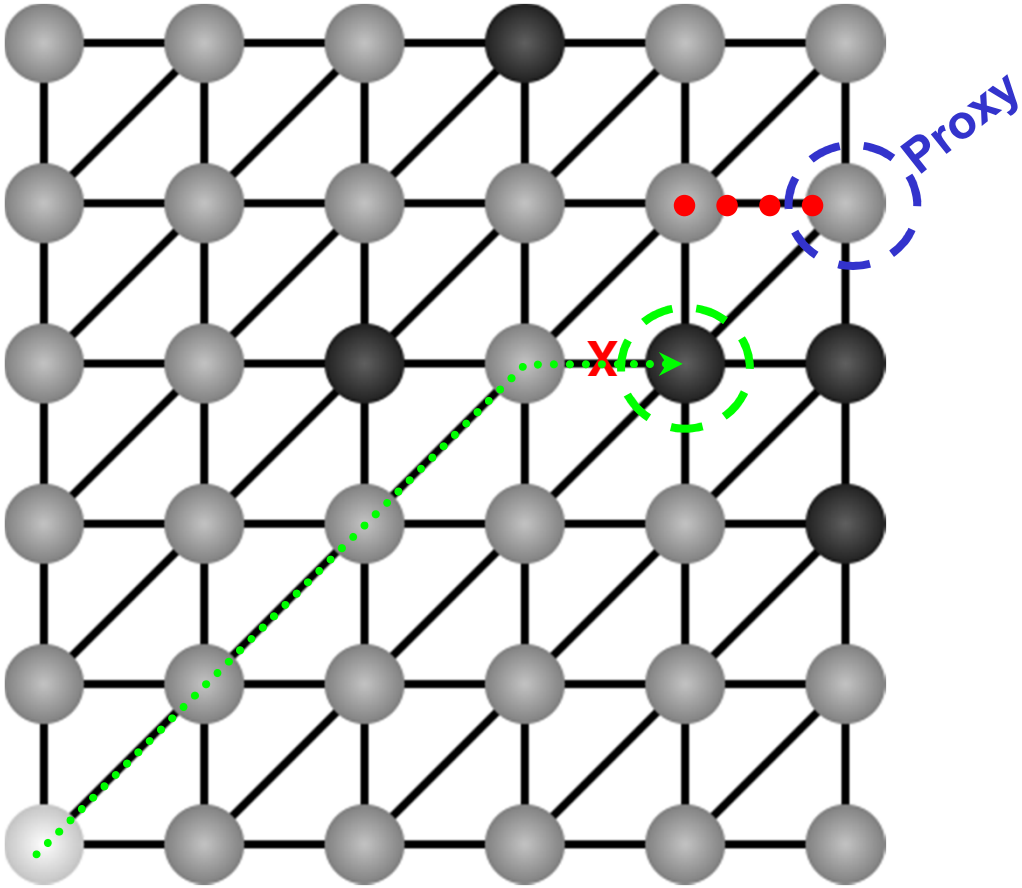
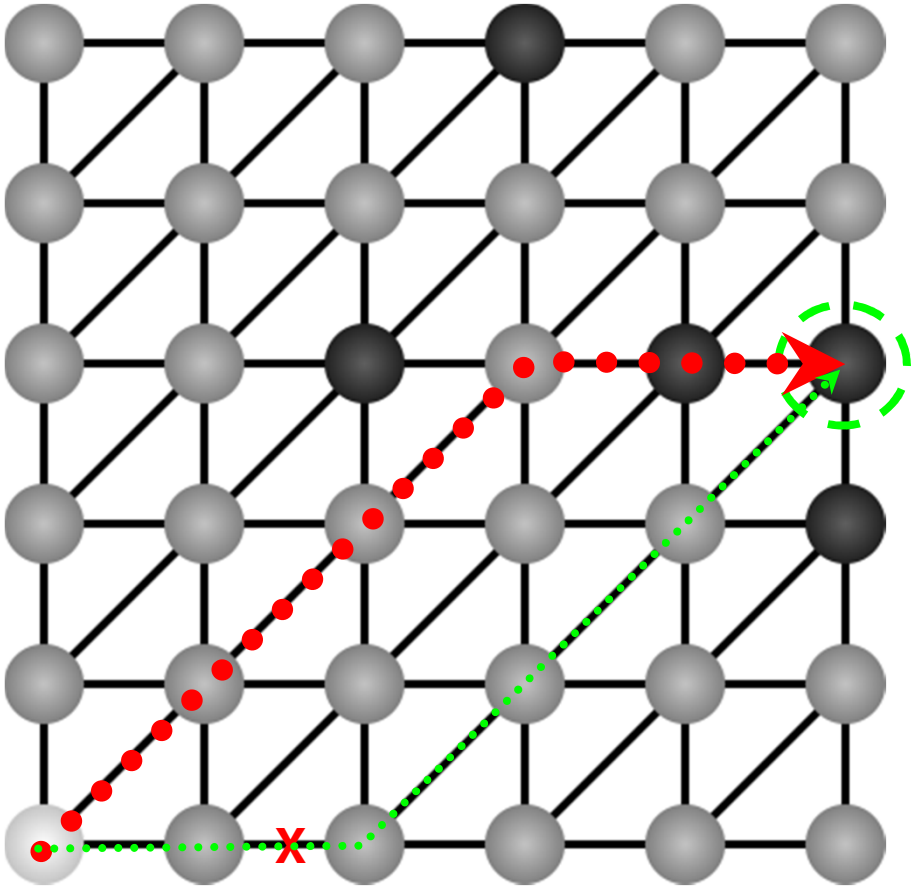
Diverting within the *minimal path* area



Look for a Proxy (*minimal path* not necessary)



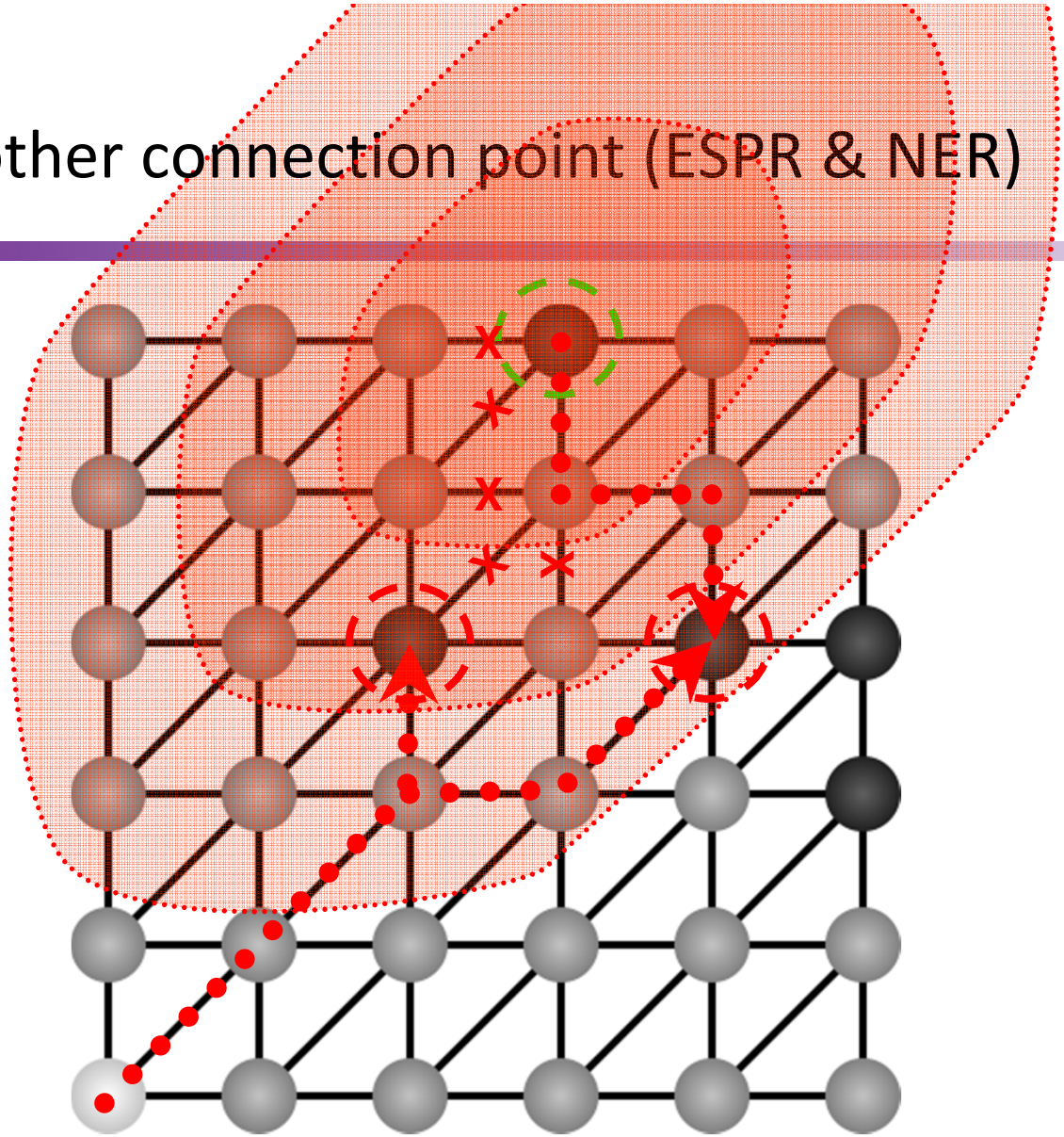
Try other order of dimensions



Cannot continue in this route

- **No Possible Diversion**
- **No Possible Proxy**

Look for another connection point (ESPR & NER)



Reaching the closest connection point is not possible

- **Paths in both dimension are blocked**
- **No Possible Diversion**
- **No Possible Proxies**