DYNAMIC STRUCTURE DISCOVERY AND REPAIR FOR 3D CELL ASSEMBLAGES

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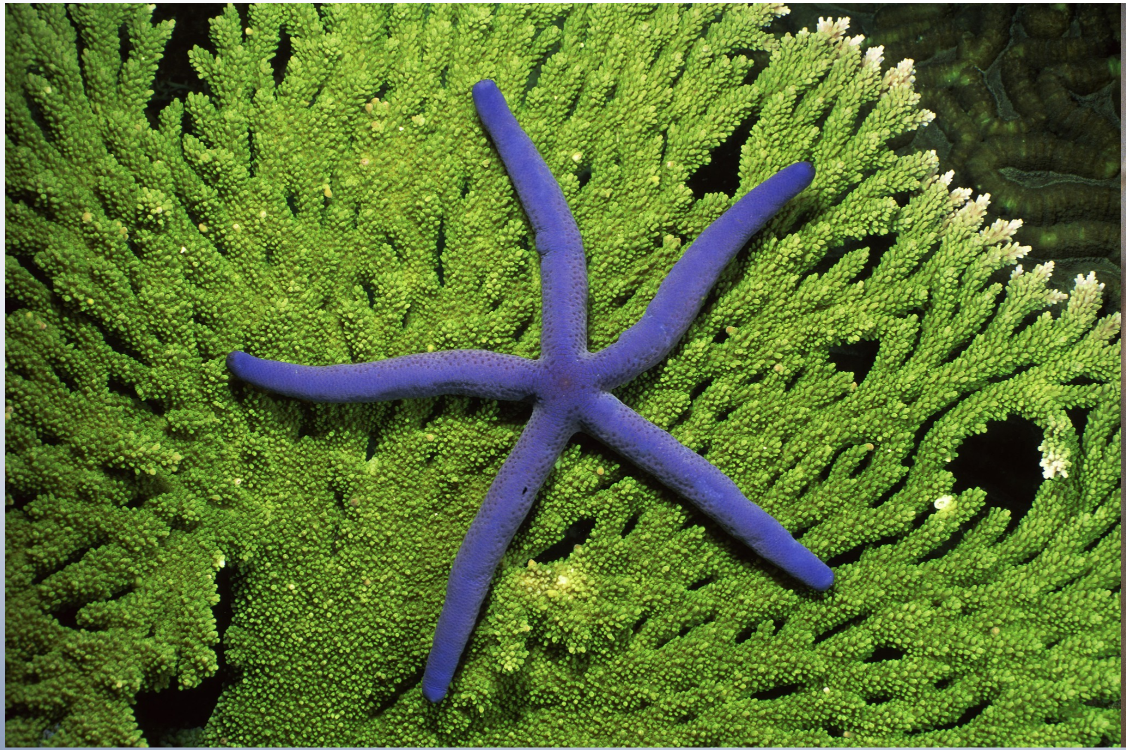
INTRODUCTION




MOTIVATION

- How does a group of cells cooperate to build and maintain complex anatomical structures?
- An answer for this question can create new hypothesis for research in areas such as regenerative medicine, aging research and degenerative disease

HOW DOES THE REGENERATION INFORMATION IS ENCODED?

- First hypothesis: Genetic Encodings
  - Morphological information is stored in and recovered from gene expressions

RELATED WORK

- The problem of structural maintenance has been approached by the artificial life community through the use of genetic algorithms, agent-based models and cellular automata
- Overall, all past approaches have been used some kind of genetic encoding.

GENETIC ENCODING DRAWBACKS

- Evidences have been found that a genetic encoding approach is not valid in all cases.
  - For example, ectopic growth on deer’s antlers after a injury persists through several subsequence shedding and regenerations

DYNAMIC MESSAGING MECHANISM

- Does not rely on any genetic encoding
- Morphological information exists across cells
- Behavior of cells depends on the messages they receive from neighbors cells
- Critical advantage: it can dynamically learn and maintain new morphologies using the same mechanism

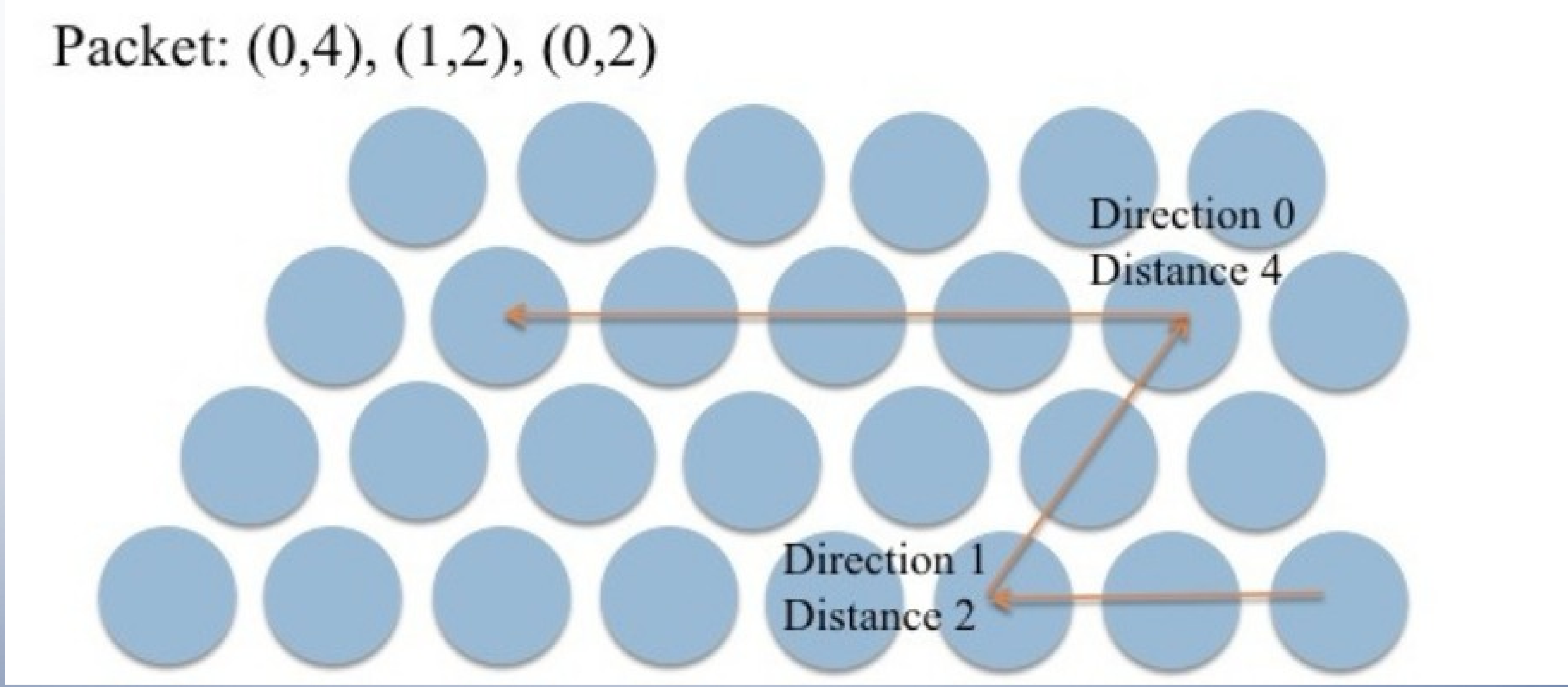
THE COMMUNICATION MODEL

- An agent based model that uses a dynamic messaging mechanism and can discover the morphology of a 3D cell structure, and then maintain this structure indefinitely, in the light of random damages that occur as part of natural aging

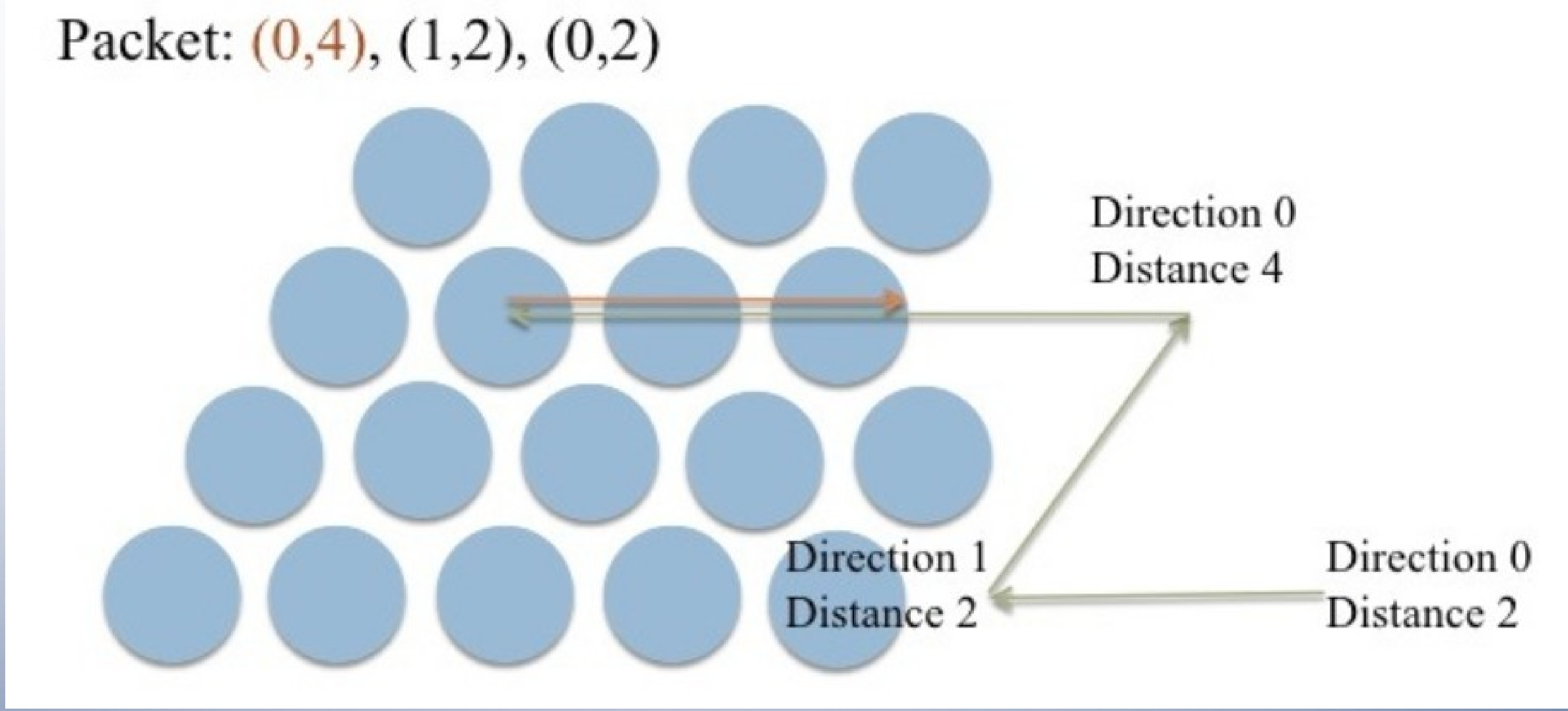
DISCOVERY AND REGENERATION

- Cells send messages to other cells containing information about the path that those messages traveled.
- Then those message packets ”backtrack” verifying if there exists a missing cell in the previous path, repairing it.

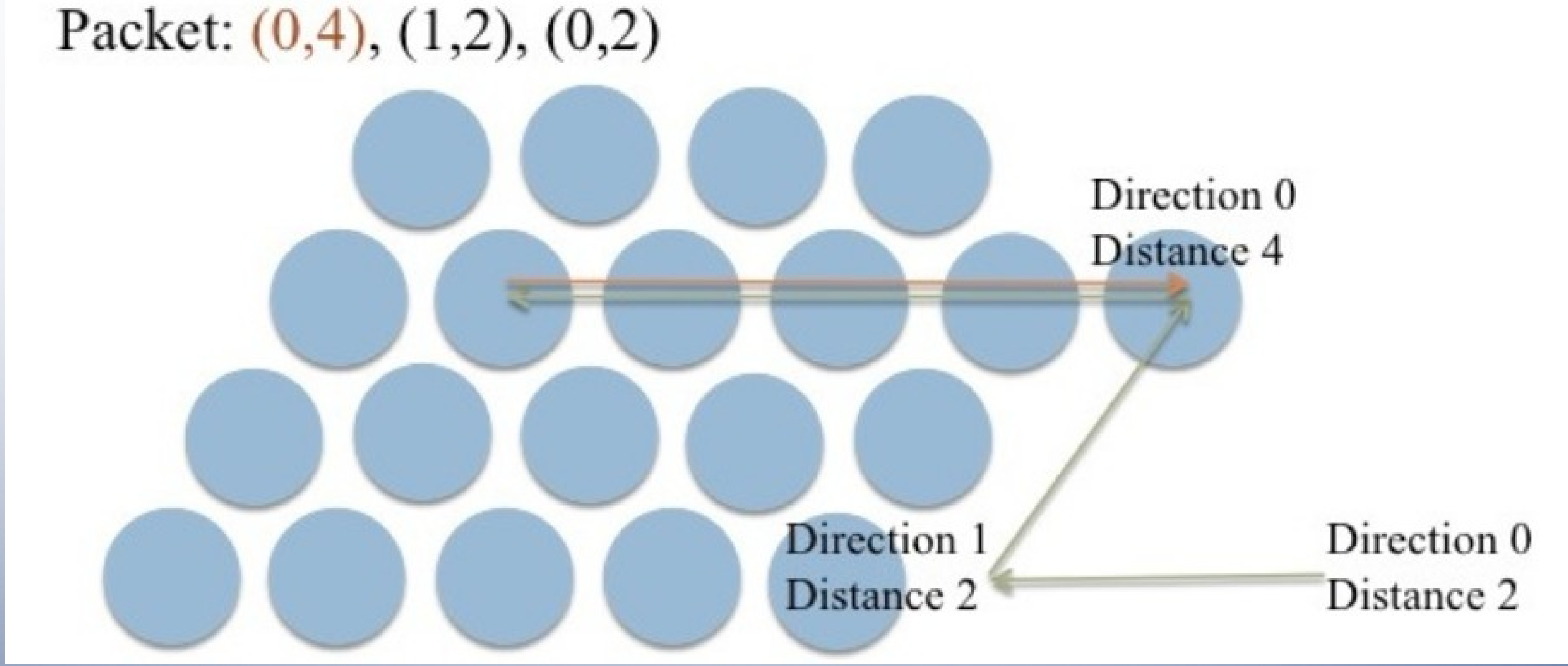
DISCOVERY


Packet: (0,4), (1,2), (0,2)
Direction 0
Distance 4
Direction 1
Distance 2

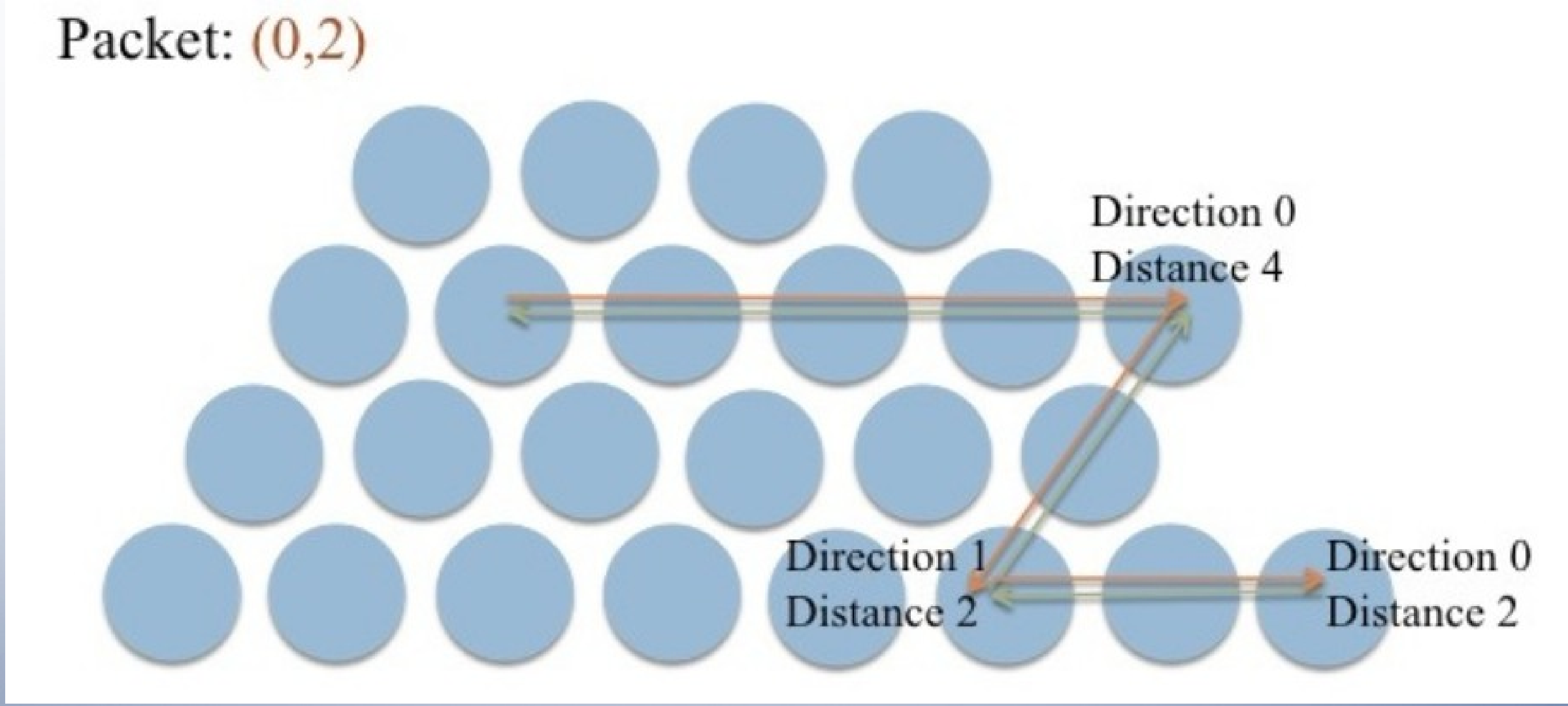
REGENERATION



REGENERATION



REGENERATION



PLANARIAN FLATWORM

MODEL PARAMETERS

- Frequency of packets
- Minimum vectors to hold a packet
- Minimum length of the top vector
- Probability of bending
- Minimum number of bends before backtracking

SIMULATION EXPERIMENTS

- Goal: verify if the model is capable of maintaining the structure of an organism over time even though random cells are dying over time
- 3D structure containing 8 layers with 339 cells per layer – total 2712 cells
- Each cell contains 12 neighbors

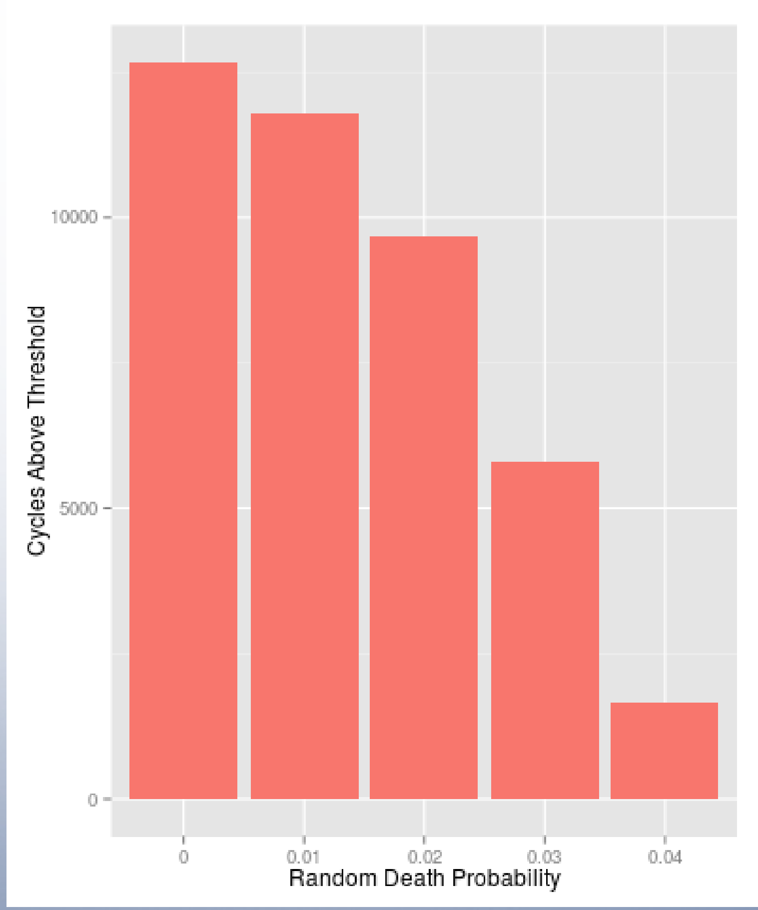
SIMULATION EXPERIMENTS

- We ran the simulation for 500 cycles
- We expect the structure has at least 90% of living cells in all cycles
- Random death probability: 0%, 1%, 2%, 3% and 4%
- Packet frequency: [1,4,7,10,13,16,19,22,25,28,31]
- Min vectors to hold: [1,3,5,7]
- Min top length to bend: [1,3,5,7]
- Bend probability: [0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0]

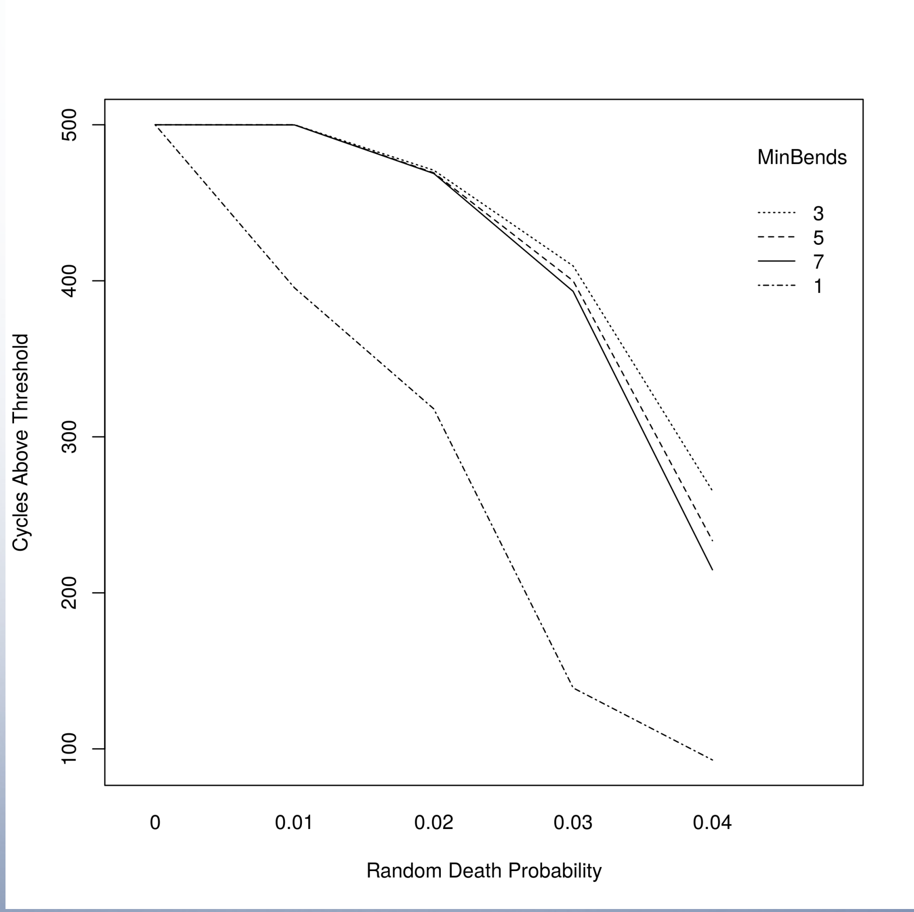
RESULTS

- 50688 data points with death probability greater than 0
- In 28961 data points the structure was maintained

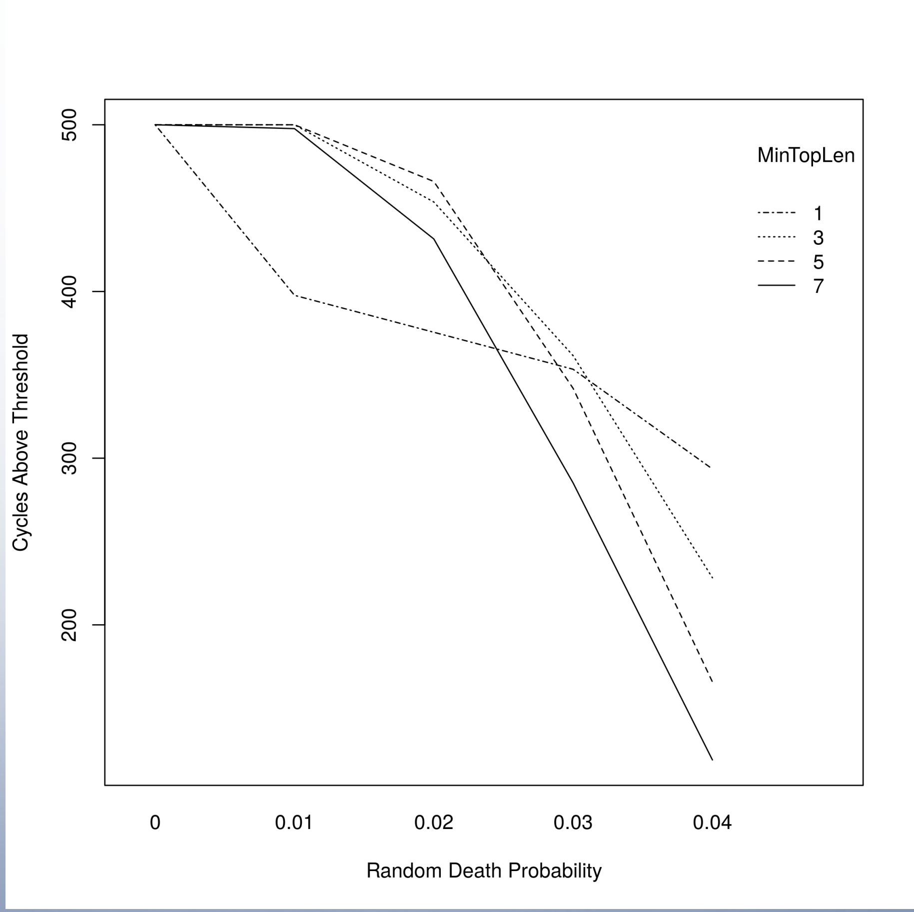
RESULTS – RANDOM DEATH PROBABILITY



RESULTS – BENDS BEFORE BACKTRACKING



RESULTS – LENGTH BEFORE BENDING



DISCUSSION

- We hypothesize that it is possible to regenerate the worm from various systematic cuts where a large part of the body is removed
  - For that, it is necessary that a subset of alive cells holds packets that cover all removed cells which would be regenerated during backtracking

DISCUSSION

- Proposed mechanisms are general enough to work for a very large set of structures.
- A structure will be maintainable depending on how cells die and how many bends packets can have.
    - More complex structures need more bends to cover them all

CONCLUSION

- Agent based model of structure discovery and repair
- As future work, we would like to perform non-equally distributed cell deaths (e.g., cluster deaths)
- We also would like to investigate the regeneration from cuts that *in vivo* worms present