# Energy Harvesting in-vivo Nano-Robots in Caterpillar Swarm

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Joint work with Shlomi Dolev, Sergey Frenkel, Michael Rosenblit and Ram Prasadh Narayanan

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# Introduction

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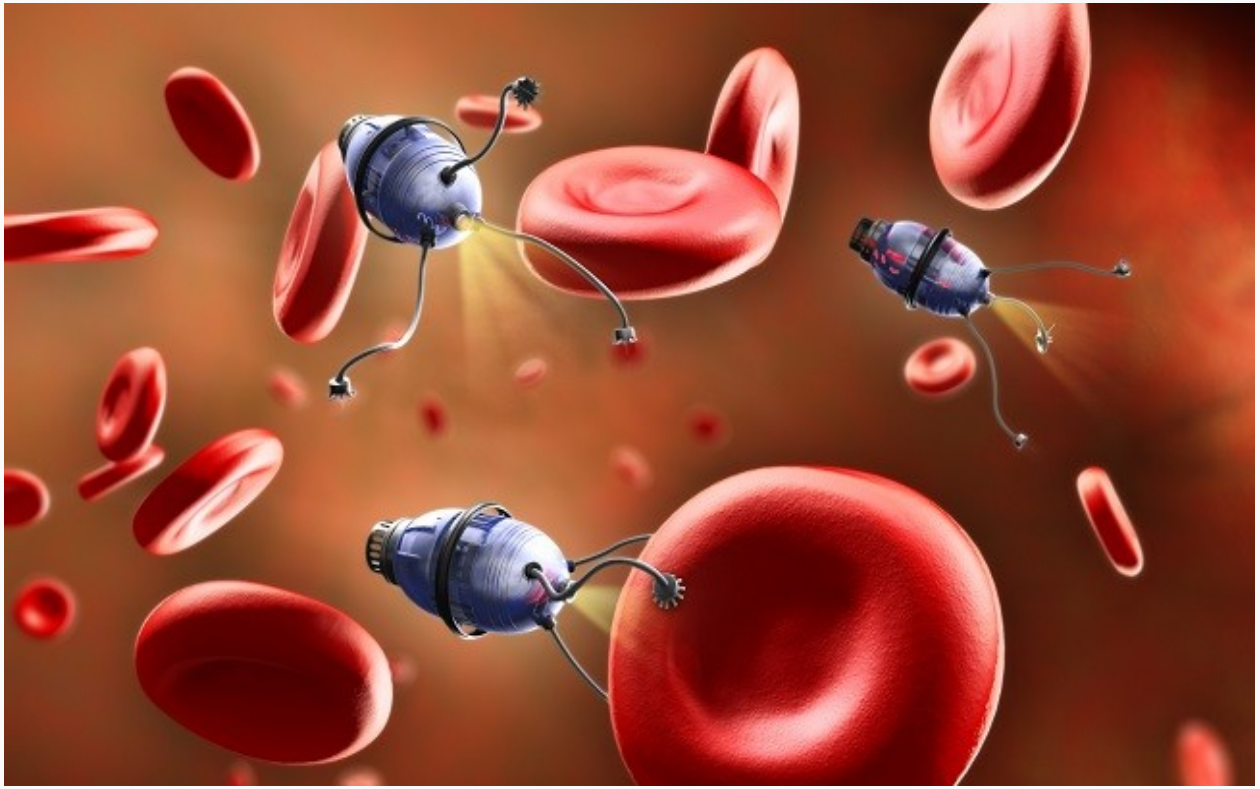
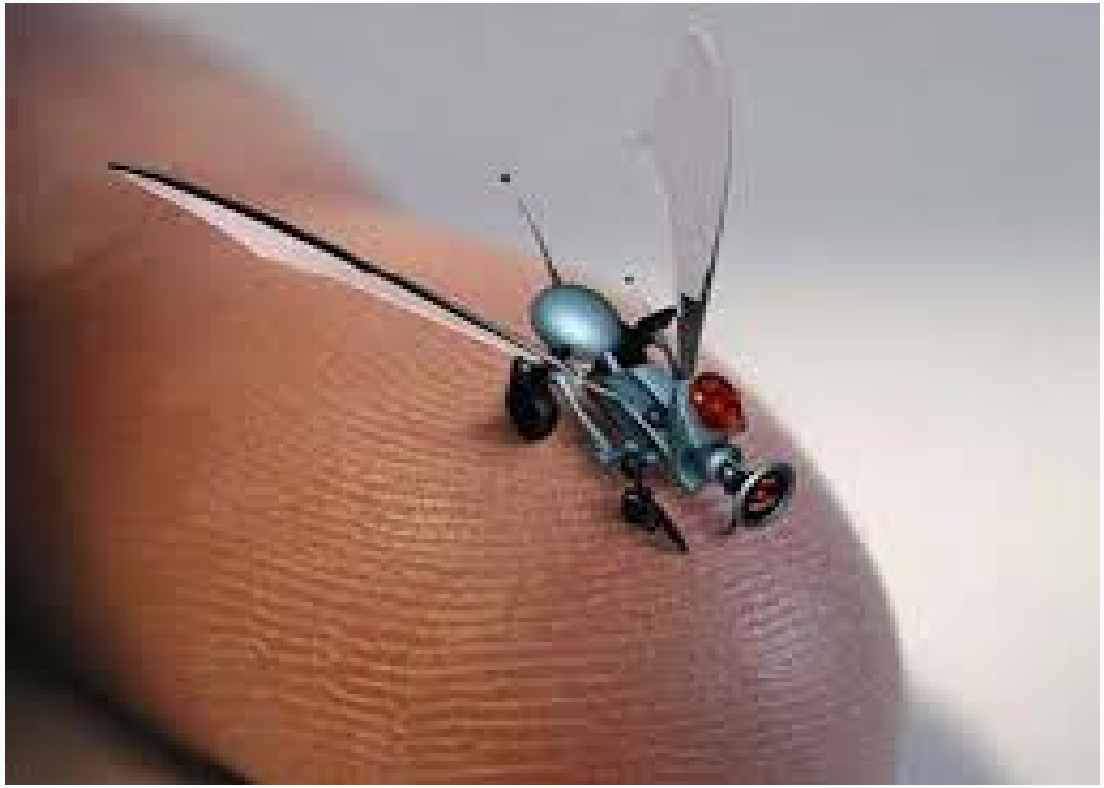


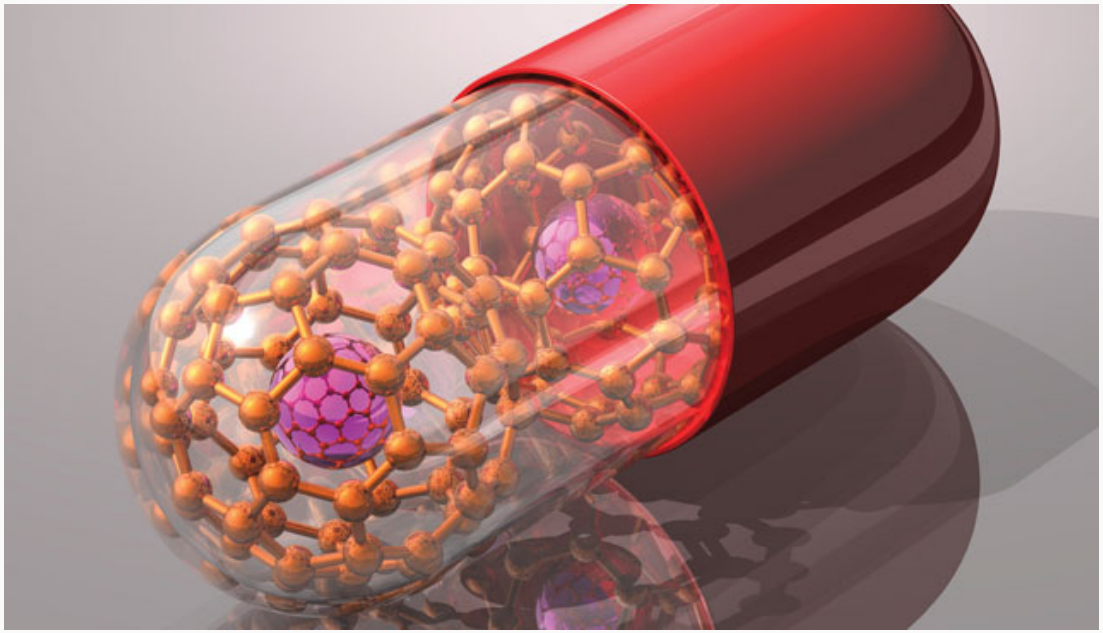
http://www.asianscientist.com/wp-content/uploads/bfi_thumb/The-Era-of-Nanorobots-How-Technology-Is-Reinventing-Medicine-2z5xi53wfuxmryvgbi2gw0.jpg

# Introduction



https://doowansnewsandevents.files.wordpress.com/2013/04/nano-bot.jpg?w=760

# Nanomedicine Application



http://www.the-scientist.com/August2014/nanomedicine.jpg

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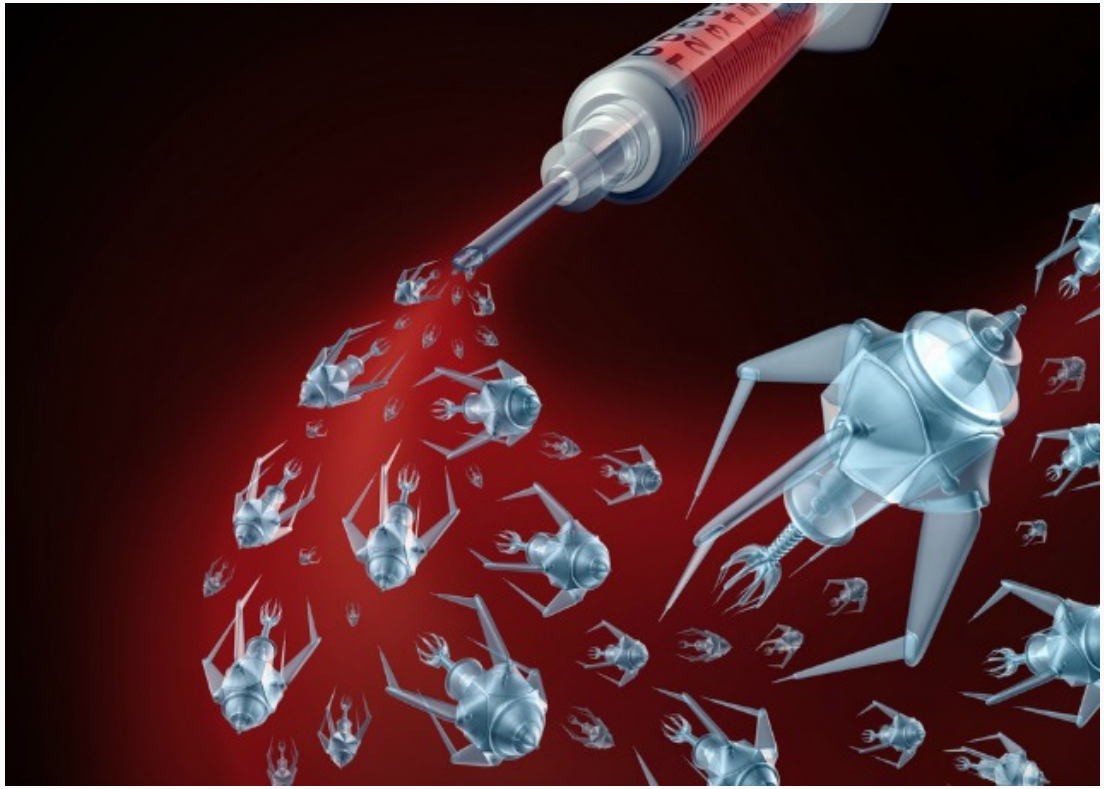

www.sovhealth.com/wp-content/uploads/2016/03/Dana_Series1_SacovHeath_Nano-Drug-Delivery-Systems_20160324_SLM.jpg

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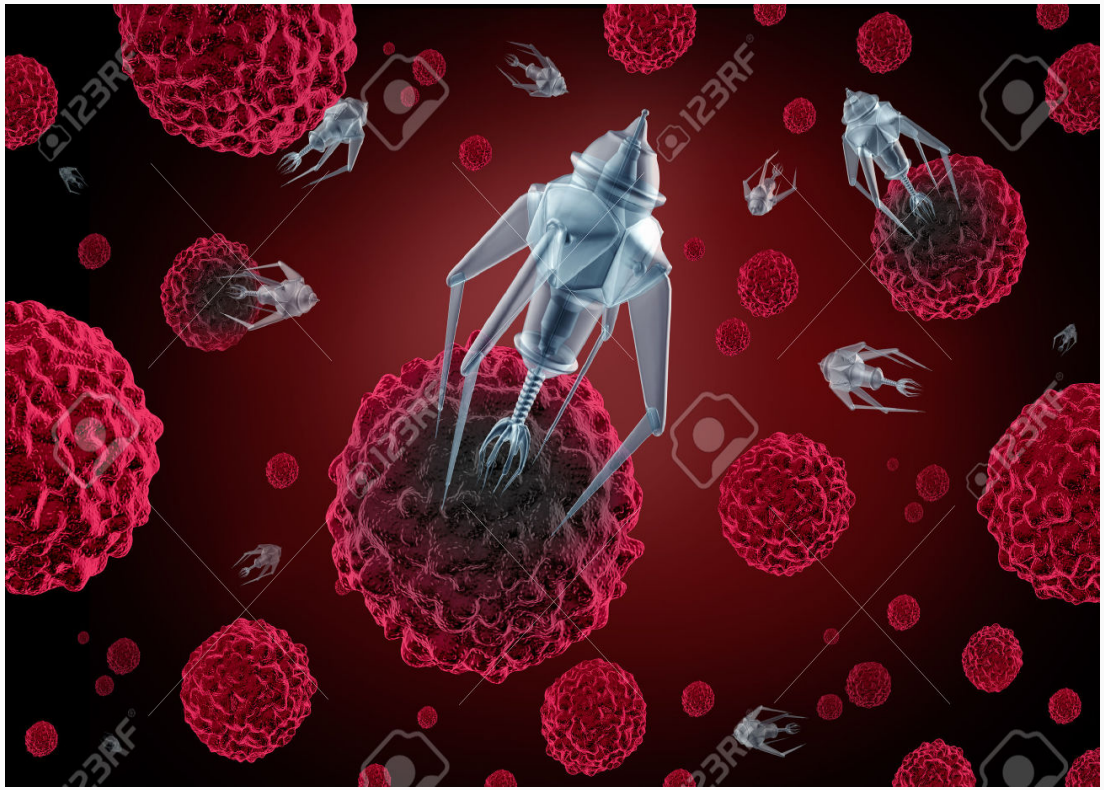

http://previews.123rf.com/images/lightwise/lightwise1504/lightwise150400074/39281323-Nanotechnology-medicine-concept-as-a-group-of-microscopic-nano-robots-or-nanobots-programed-to-kill–Stock-Photo.jpg

# Requirements

## Challenges

- Dynamic decision making
- Coordinated behavior
- Energy Harvesting techniques etc

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H. Abelson, D. Allen, D. Coore, C. Hanson, G. Homsy, Jr. T.F. Knight, R. Nagpal, E. Rauch, G. J. Sussman, and R. Weiss. Amorphous computing. Commun. ACM, 43(5):7482, May 2000.

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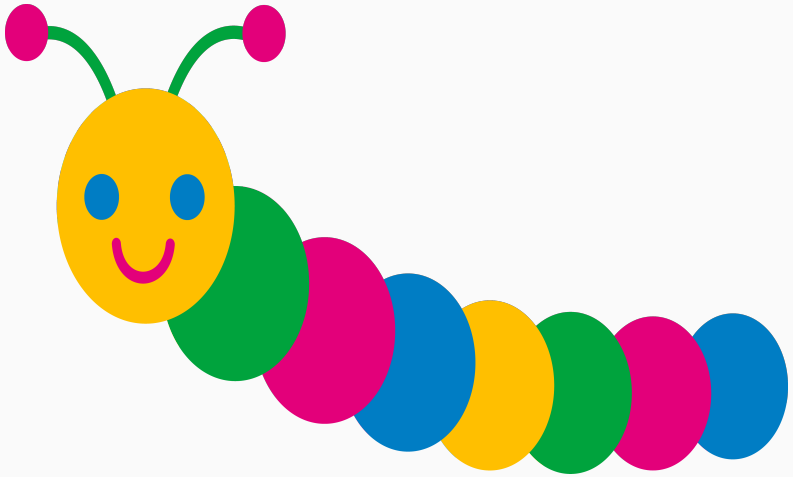
# Motivation

# Caterpillar Swarm

1. Caterpillar Swarm Behavior http://www.wired.com/2013/07/why- are-these-caterpillars-climbing-over-each-other-the-surprising-science- behind-the-swarm/
2. http://player.mashpedia.com/player.php?q=IcMOdPJe0YU
3. Why do caterpillars swarm. http://www.empiricalzeal.com/2013/07/23/ why-do-caterpillars-swarm-we-built-a-game-to-find-out/

# Plain Swarm



http://cliparts.co/cliparts/qTB/Xaz/qTBXazbEc.png

# Layered Swarm

# Layered Swarm: Increased Speed

- **Average speed of a caterpillar in the swarm is** $\frac{v_0(l+1)}{2}$

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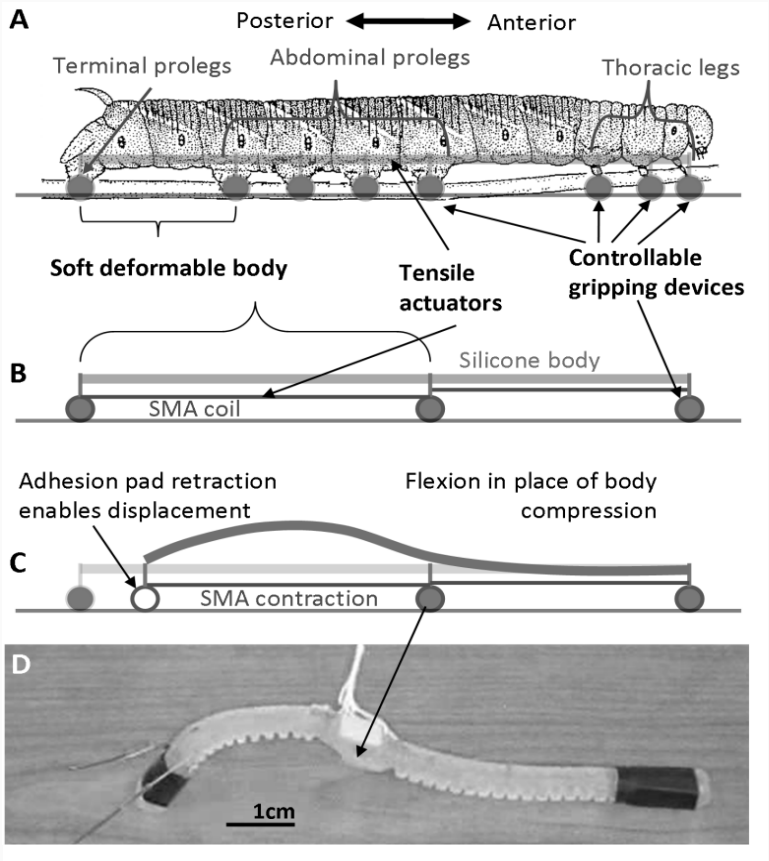
1. https://www.youtube.com/watch?v=OVM2rrqPl68"
2. Caterpillar Swarm Behavior http://www.wired.com/2013/07/why-are-these-caterpillars-climbing-over-each-other-the-surprising-science-behind-the-swarm/.

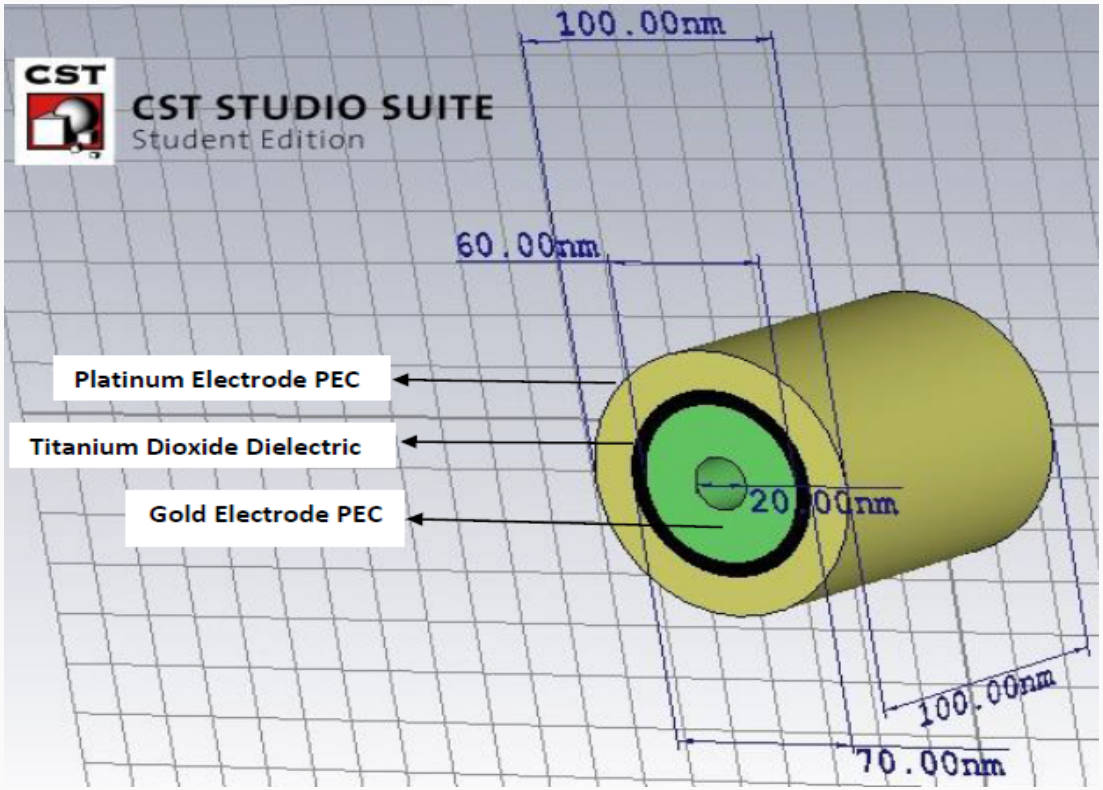
# Caterpillar Robot




B. A. Trimmer, H. T. Lin, A. Baryshyan, G. G. Leisk, and D. L. Kaplan. Towards a biomorphic soft robot: Design constraints and solutions. In 2012 4th IEEE RAS EMBS International Conference on Biomedical Robotics and Biomechatronics (BioRob), pages 599?605, June 2012."

# Proposed Design

# Characteristics of Platinum and Gold Electrodes



# Obtained and Required

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- Amount of charges stored by a single Nano robot $2 * 10^{-14}$ to $10^{-13}\mu C$
- Electrical Charges needed for Biological destruction of a Cellular Tissue $21 - 30\mu C/cm^2$.

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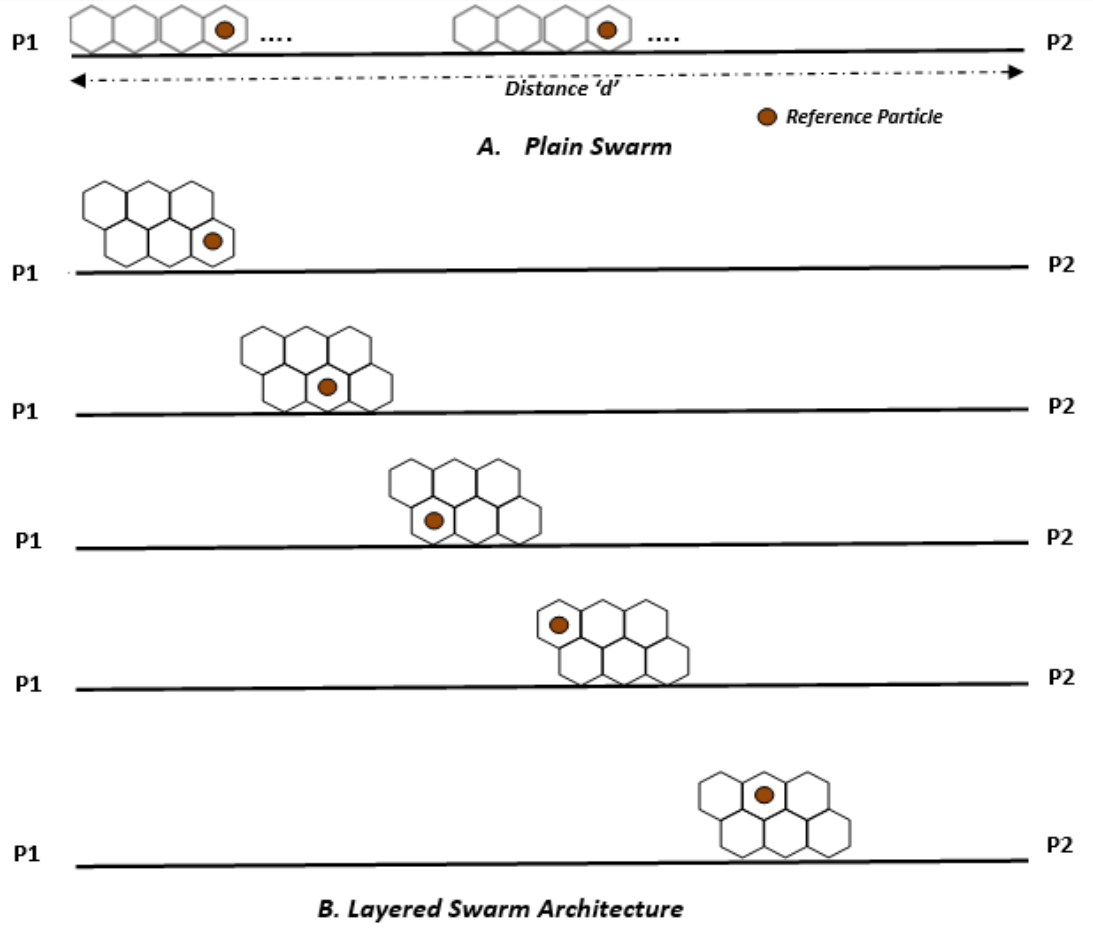
M. A. Rossi. Energy-releasing carbon nanotube transponder and method of using same , United States Patent 8788033 B2, 2014.

## Mimicking Caterpillar Swarm Technique

# Energy Harvesting in-vivo Nano-Robots in Caterpillar Swarm



# Homogeneous Robots

http://previews.123rf.com/images/vectomart/vectomart1109/vectomart110900167/10703846-illustration-of-human-icon-standing-on-chess-board-Stock-Vector.jpg

# Energy Harvesting in-vivo Nano-Robots in Caterpillar Swarm

- $E = (mv_0^2)/2 = (2mv_1^2)/2 = \cdots = (imv_{i-1}^2)/2$

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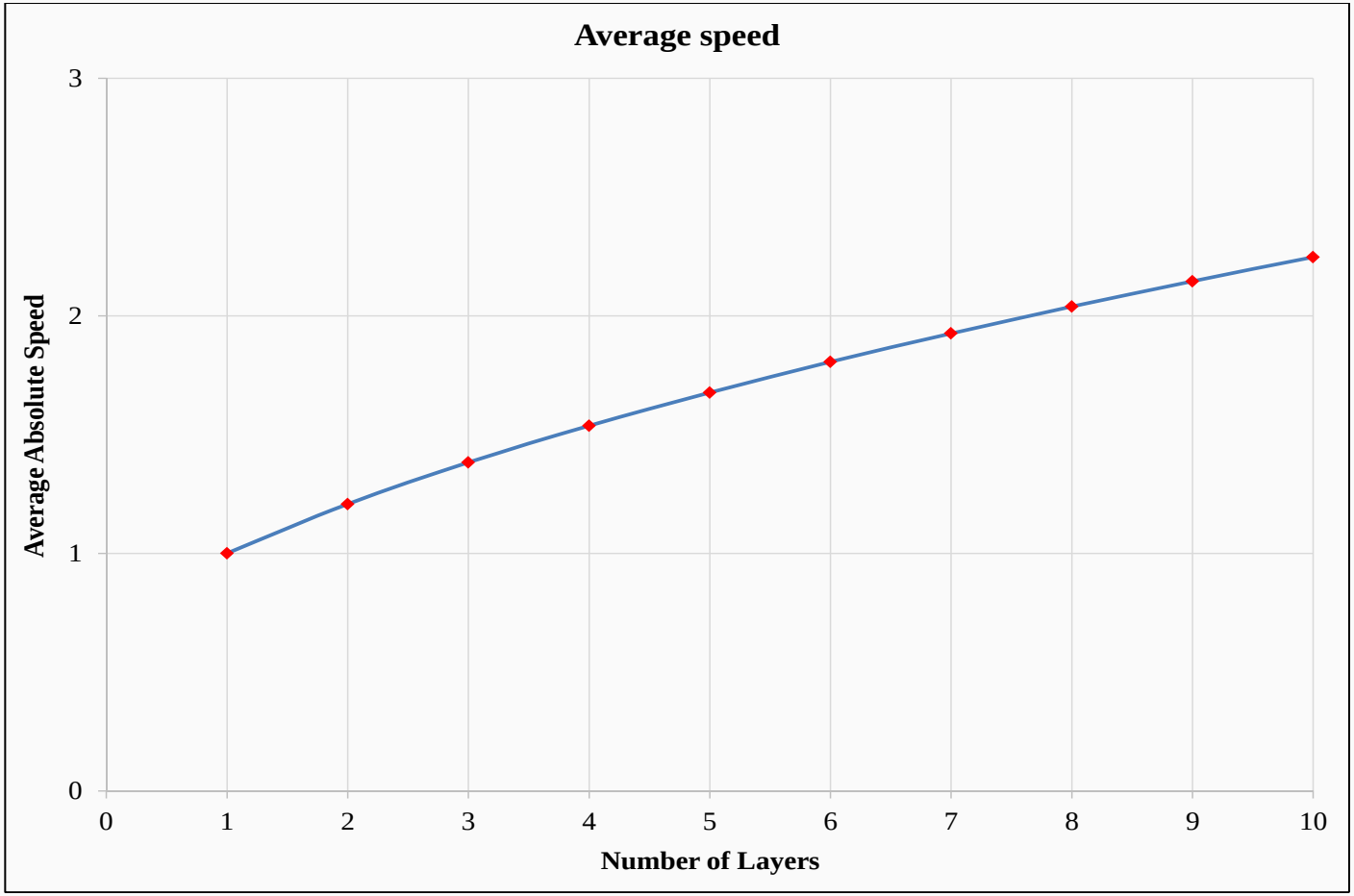
- Absolute speed, $av_i = \Sigma_{j=l}^{i} v_0/\sqrt{j}$
- Average speed, $as_l = \frac{v_0}{l}\Sigma_{i=1}^{l}\sqrt{l}$

# Average Speed of a Nanorobot



## Result

# Energy Harvesting in-vivo Nano-Robots in Caterpillar Swarm

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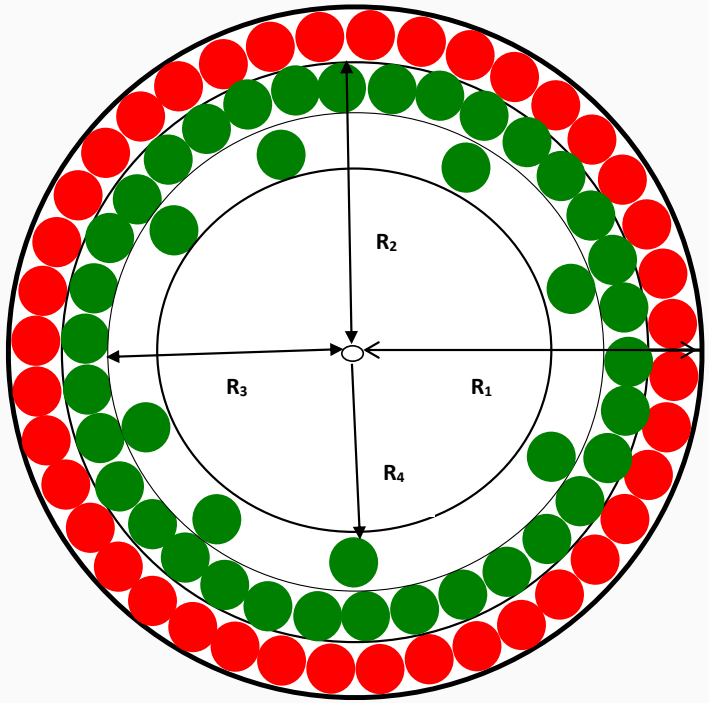
$$\frac{I}{\Sigma_{i=1}^{I}\sqrt{I}} \times t_p$$

# Folding Layers in a Pipe

# Swarm Architecture in Pipe



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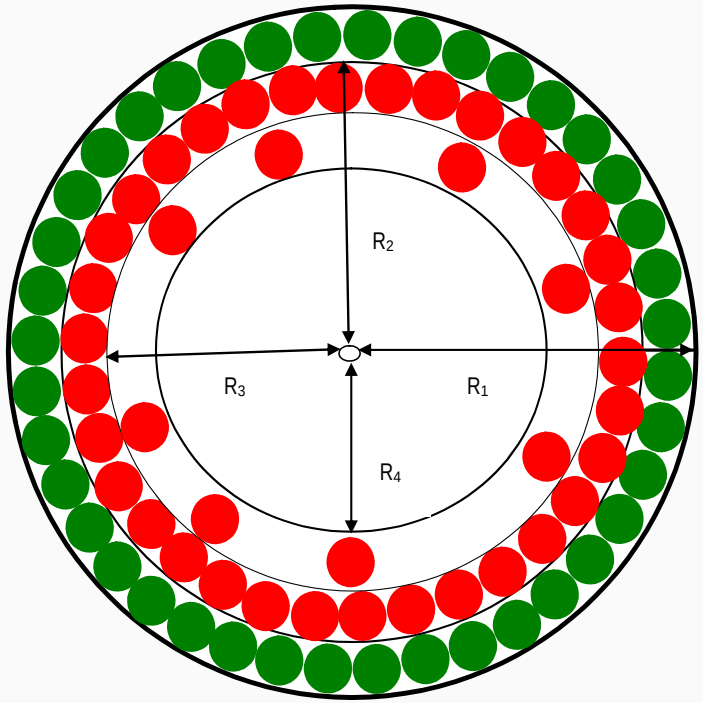

# Algorithm for Folding Layers in a Pipe

1. **Input:** $N$, $d$, $r$
2. **Output:** $l$, $x_1, x_2, \ldots, x_l$
3. $x_1 = \lfloor 2\pi(r - d/2)/d \rfloor$
4. $sigmax = x_1$
5. $overflow_1 = 0$
6. $l = 1$
7. $r_1 = r - d/2$
8. **while** $sigmax < N$ and $r_l > \frac{3d}{2}$ and $overflow_l < \lfloor \frac{x_l}{2} \rfloor$
9. **do**
10. $\quad l++$
11. $\quad r_l = r - ((l-1) \cdot d + d/2)$
12. $\quad max_l = \lfloor 2\pi r_l/d \rfloor - overflow_{l-1}$
13. $\quad overflow_l = overflow_{l-1} + x_1 - max_l$
14. $\quad x_l = max_l - overflow_{l-1}$
15. $\quad sigmax = sigmax + x_l$
16. **od**

# Conclusion

# Summary

We have proposed a design of nano-robots that harvest energy from the blood serum, energy that can activate

- nano-transistors,
- logic gates and circuits to control the activities of the nano-robot
- coordinate, collaborative to achieve the common goal.

# Questions?

# Thank You!