A conversation with Chris Phoenix on August 20, 2014

Participants

- Chris Phoenix – Co-Founder and Director of Research, Center for Responsible Nanotechnology
- Nick Beckstead – Research Fellow, Future of Humanity Institute, Oxford University

Note: This set of notes was compiled by GiveWell and gives an overview of the major points made by Mr. Phoenix.

Summary

GiveWell spoke with Chris Phoenix as part of an Open Philanthropy Project investigation of atomically precise manufacturing (APM) as a potential global catastrophic risk. Conversation topics included: problems associated with APM, potential development pathways, possible interventions, and other people to talk to about this risk.

Catastrophic risks from nanotechnology

Risks from current nanotechnology, such as industrial accidents and the proliferation of new types of chemicals, are most likely not catastrophic. The more probable catastrophic risks from nanotechnology are longer-term concerns related to atomically precise manufacturing (APM)/molecular manufacturing (synonymous terms). In a mature form, APM may allow for general-purpose, programmable nanofactories which could assemble a wide variety of structures (including more nanofactories) atom-by-atom. A machine of this kind could increase in number at an exponential rate if given the necessary feedstock. A factory that could copy itself in a day could yield a billion factories in a month.

There has been some popular concern over whether advances in APM could result in a doomsday scenario referred to as "grey goo." Mr. Phoenix does not think this is the main threat from nanotechnology, in part because making it would serve no practical purpose and would require a range of challenging technological advances, such as:

- A miniaturized, mobile nanofactory
- A miniaturized, mobile feedstock processor
- A small, efficient computer to control each machine
- A harvesting system to gather the necessary materials
- A size that is too small to clean up or dispose of easily

In Mr. Phoenix's view, it is likely that other risks from APM will emerge significantly before the grey goo scenario becomes a realistic possibility. Nevertheless, Mr. Phoenix believes it is likely that someone will eventually try to make grey goo.

Mr. Phoenix is most concerned about the possibility that, in the future, mature APM technology could be used to create new weapons and manufacture more of them at a rapid exponential rate. Examples of such weapons may include:

- Mosquito-like machines that can administer a deadly substance
- Objects that change a microclimate by concentrating the sun's rays

In addition to manufacturing, general-purpose nanofactories would speed prototyping and product development because the factories could immediately build parts on site, leading to a faster design/prototype/test cycle.

These advanced capabilities could, if realized, result in geopolitical uncertainty and instability. For instance, if one nation had a sufficient lead in APM capabilities, it's possible that rapid exponential growth in their supply of new weapons could give them a decisive military advantage over other nations. Anticipation of this could result in an arms race between nations, or one nation making a pre-emptive strike. For example, one nation might be tempted to launch a pre-emptive attack on another nation that was going to gain access to this technology because advanced APM-based defenses might not be able to stop attacks by offensive APM. APM will provide a diverse and rapidly-shifting array of attacks and defenses, potentially making it difficult to rely on a MAD-like calculation to prevent war. Therefore, a nation might be motivated to devastate the tech base of another nation, or impose massively intrusive surveillance on it, in order to keep it from developing APM.

Benefits of atomically precise manufacturing

General-purpose APM could help with environmental, medical, and poverty-related issues. For example:

- Machines could be designed to remove excess carbon from the atmosphere
- Improved solar cells could be designed to produce cheap solar energy

Mr. Phoenix thinks APM may be an unusually effective way of reducing deaths caused by lack of access to technologies because anyone with a desktop manufacturing system and enough feedstock could build what they need.

Mr. Phoenix is hopeful that potential threats from nanotechnology might not materialize. Current biotechnology supports his hope: there are many potentially dangerous uses that have not been pursued. Gasoline is another technology that might have sounded scary but whose incendiary uses turned out not to be a major threat.

Two possible development paths

APM could develop in at least two ways:

1. A potentially secret "Manhattan Project"-like program run by the government
2. A public community of hobbyists (so-called "makers") working in loose collaboration or competition to further the field

Manhattan Project

Under this scenario, one or more governments would secretly develop the technology. A government could simultaneously develop several component technologies. It could also use a "design-ahead" approach, in which designs are made in advance for use as soon as necessary technologies become available.

There might be no warning if APM developed this way. Some may suggest that we'd notice if many top physicists and chemists stopped publishing, as one might expect if they were recruited by a Manhattan project. A government would need to hire physicists and chemists for this project, but not necessarily top physicists and chemists. As a result, an observer may not notice that the scientists who had been hired for the project were not participating in regular activities, such as publishing other research. In Mr. Phoenix's view, this approach could potentially take as few as 10 years from when it began.

Makers

Under this scenario, a public community of makers (including hobbyists and academics) would develop the technology in a piecemeal, gradual manner, leaving time for society to adjust to advances.

If there were a well-conceived seed effort, comparable to the RepRap project, aiming at a limited goal of building computer-controlled molecular tools that could build more such tools, Mr. Phoenix believes there would be a reasonable probability of achieving cubic micron level, non-exponential APM in 5 years but would not be capable of producing a nanofactory soon because such a project would require too many resources and too much coordination.

Mr. Phoenix believes the maker scenario is safer than the "Manhattan Project" scenario because it would lack the military component, would be more gradual, and would make it less likely that one country would have a sufficient lead in APM capabilities to trigger the geopolitical instabilities described above. This is a reversal from his previous position.

Milestones

In the "maker" scenario, the most likely development pathway would involve DNA self-assembly. This would require a collection of advances, including:

<u>Motors for nano-robotic actuators</u>

These would permit building on the micron scale. This state of technology might last 5 to 10 years. Molecules could be organized at the rate of billions per second, not fast enough to quickly produce anything large.

<u>Access to cheaper ways of detecting small objects</u>

100 nm is the "diffraction limit" (smallest visible scale) for a light microscope. Without access to tools capable of detecting objects closer to 1 nm, hobbyists may not be able to see what they make. Some optical systems currently exist with resolution down to 5 nm. These are not available to hobbyists now but they might be in 5 years.

For development along either pathway, Mr. Phoenix would expect to reach the following milestones prior to the development of advanced APM technologies:

The first “proto-nanofactory”
This would not have an onboard computer. Material processing might be done using a robot arm.

General consensus that it is doable
This would prompt many more people to work on APM. A group that publicly claims to have a credible path could accelerate the industry substantially. The group would probably aim to achieve APM by building a cubic micron of micropolymer.

For exponential APM, milestones would likely include:

- Integrated nanoscale computers
- Assembly-line building systems, rather than a robot-arm approach
- Special materials that are strong enough and conductive enough to be used in APM
    - These material needs could especially delay progress in exponential manufacturing.

Current funding
Though there is a large amount for nanotechnology in general, very little of it is relevant to APM. Mr. Phoenix believes that current spending on APM is on the order of $1 million per year, assuming there is no secret development project underway.

Interventions
There is a high level of uncertainty about which interventions would be most likely to prevent potential risks from nanotechnology because of uncertainty about:

- What molecular manufacturers might decide to build
- How weapons designers would use APM
- How APM might factor into military strategy
    - For example, would it be easier to defend against nanofactories or to use them offensively? (Based on the scale, quantity, and variety of possible weapons, Mr. Phoenix thinks it would be much easier to use them offensively than to defend against nanofactory-built weapons.)

Understanding the threat
A private funder could try to better understand the potential risks of nanotechnology by convening a group of experts to check Mr. Phoenix’s and others’ analyses of these issues to decide (a) whether a “Manhattan Project” approach would likely lead to devastating war and (b) whether the technology is too inherently dangerous to be pursued along the maker-based path of development. The goal of this group of experts would be to help assess which development pathways would be safest.

Promoting the safest approach

Scientific research
If the group of experts decided that the technology should be developed along the maker path, the next step would be to encourage makers to work on it. To do this, a funder could:

1. Hire a small group of scientists (a biochemist, a mechanical engineer, a condensed-matter physicist, and maybe an industrial designer) who think the project is interesting and are eager to see how far they can take it.
2. Fund them and their graduate students to design inexpensive packages of tools and projects that hobby groups could use.
3. Fund a research group to study what kind of chemistry could be used in molecular construction projects and how to build nanoscale motors.

The Replicating Rapid Prototyper (RepRap) project could serve as a model for promoting the maker path. In 2005, Dr. Adrian Bowyer started the initiative to make a macro-scale plastic fabrication system designed to build all the plastic pieces to replicate itself. Though crude in its early stages, the project progressed significantly because of advances in 3D printing.

Education and outreach
In the mid-1990s, scientists working on APM started to face career limitations. Mr. Phoenix thinks this was because of: a) skepticism about whether APM was possible and b) changes in attitudes among leaders in the nanotechnology industry—specifically, many leaders in this industry (such as the National Nanotechnology Initiative and the Nanobusiness Alliance) decided to oppose APM because they worried that perceived risks involving APM might cause policymakers to reduce nanotechnology funding more broadly.

To promote the maker path, a philanthropist could seek to reduce skepticism towards APM among policymakers, industry leaders, and academics and negative career consequences for scientists and engineers who work on it. However, Mr. Phoenix is not aware of promising ideas for addressing these challenges.

Other people to talk to:

- Eric Drexler
- Robert Freitas
- Josh Hall
- Ralph Merkle
- Paul Rothemund
- Chris Schafmeister
- Jim Von Ehr

Other groups to learn about:

- Foresight Institute
- Center for Responsible Nanotechnology (CRN)
- Institute for Molecular Manufacturing (IMM)
- Robert Freitas' laboratory
- Zyvex

Mr. Phoenix said to ask Robert Freitas, Paul Rothemund, and IMM about other groups working on APM.

Recommended reading:

- CRN's studies of whether APM is possible and how it might develop

All GiveWell conversations are available at http://www.givewell.org/conversations