苏菲拉底 THE SOPHIE LAB

本期追问

AI 能在多大程度上接管数学家的创造性工作?

数学如何从个人英雄时代走向「大数学」协作?

当认知变得廉价，人类还需要锻炼思考能力吗?

视频精读 VIDEO STUDY

Can AI Prove It? Terence Tao on “Big Math” and Our Theoretical Future | The Futurology Podcast

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好视频，值得精读

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导读 视频总结

本期讲者

陶哲轩（Terence Tao） UCLA数学教授，2006年菲尔兹奖得主，被广泛视为当代最杰出的数学家之一。以格林—陶定理、压缩感知等成果著称，近年致力于推动AI辅助、形式化验证与大规模众包协作数学。

Don Nakagawa 《Futurology》播客主持人，也是该节目的执行制作人之一，节目聚焦科技与社会的未来议题。

第一部分　全文对照 · 附页边注释与生词标注

01　开场：陶哲轩与本期主题

0:00 Don Nakagawa（主持人）

Hi, I'm Don Nakagawa, the host of Futurology. And in this episode, I spoke to [music] Terrence Tao. Terrence is a worldrenowned mathematician. He is winner of the Fields Medal, which is [music] considered the Nobel for mathematics. Terren's work on the forefront of theoretical mathematics, is really where he thrives. [music] What's interesting about Terrence though is [snorts] he actually really appreciates the collaborative [music] process and has worked really hard to push forward collaborative mathematics which is not a given. In recent years what we're seeing is a lot of people from mathematics departments are going into technology companies and the rate of application from theory [music] into you know products that are on the shelf is happening faster [music] and faster. We also talked about AI and how AI could actually help and whether AI will, you know, leapfrog what humans are capable of doing. In Terren's opinion, that's not going to happen very quickly. There are certain things that

嗨，我是 Don Nakagawa，《Futurology》的主持人。在这一期节目里，我采访了[音乐]陶哲轩。陶哲轩是一位世界知名的数学家。他是菲尔兹奖得主，这个奖被[音乐]视为数学界的诺贝尔奖。陶哲轩的工作处在理论数学的最前沿，这也正是他真正大放异彩的地方。[音乐]不过陶哲轩有意思的一点是[吸鼻声]他其实非常看重协作[音乐]这个过程，并且非常非常努力地推动协作式数学，而这并不是理所当然的事。近年来我们看到的是，很多数学系的人正在进入科技公司，而从理论[音乐]走向应用、走向你知道的那些摆在货架上的产品，这个速度正变得[音乐]越来越快。我们还聊到了 AI，以及 AI 究竟能怎样帮上忙，还有AI 会不会，你知道，一举超越人类的能力。在陶哲轩看来，这在短期内不会发生。有些事情 AI 可以做得非常非常好。嗯，

菲尔兹奖每四年颁发一次，只授予40岁以下数学家，被视为数学界最高荣誉。陶哲轩2006年31岁获奖，表彰其在偏微分方程、组合数学与数论等领域的贡献。

worldrenowned /ˌwɜːrldrɪˈnaʊnd/ *adj.*
举世闻名的（规范拼写 world-renowned）

forefront /ˈfɔːrfrʌnt/ *n.*
最前沿（at the forefront of 处于…最前沿）

thrives /θraɪvz/ *v.*
茁壮成长；大放异彩（thrive）

leapfrog /ˈliːpfrɑːg/ *v.*
跨越式超越（本义为跳背游戏）

1:04

AI could be really, really good at. particularly collapsing the tedious amount of work that's involved in trying to figure out what all the other theorists have done before [music] one starts to sort of push forward a theory that can be helped by AI. actually discovering what the truth of or solving a theorem that still takes human intervention and in Terren's mind is going to remain that way for a while. And now on Futurology, here is my interview with Terrence [music] Tao. Terrence Tao, welcome to Futurology.

特别是能大幅压缩那些繁琐的工作量——就是在你开始推进一套理论之前，[音乐]要去搞清楚此前所有其他理论家都做过些什么，这部分是 AI 可以帮上忙的。但真正去发现真理，或者证明一个定理，那仍然需要人的介入，而在陶哲轩看来，这种情况还会持续一段时间。现在，在《Futurology》节目中，请看我对陶哲轩[音乐]的采访。陶哲轩，欢迎来到《Futurology》。

开篇点出全片核心判断：AI擅长压缩「摸清前人做过什么」的繁琐文献工作，但发现真理、证明定理仍需人类介入——后文围绕这一人机分工展开。

tedious /ˈtiːdiəs/ *adj.*
冗长乏味的、繁琐的

human intervention *phr.*
人工介入、人为干预

02 跳级神童的成长经历

1:41 陶哲轩（穿插主持人提问）

>> A pleasure to be here. >> I'm really glad you could be with us today. I thought we'd just start by talking a little bit about your background and situating you I guess in the moments that we're going to be talking about which is a strange technosocial evolutionary moment that we're in or revolutionary moment that we're in. so I'd love to start with like tell us a bit about Terrence Tao. >> Okay. Well, I was born in Australia in the 70s. my parents came from China but I grew up in Australia. I was very much westernized. although in fact I watched a lot of American television I remember growing up and so my accent in particular is this weird mix of Australian and American. So I always loved math, always loved numbers. I competed in these math competitions at an early age.

>> 很高兴来到这里。>> 非常高兴你今天能和我们在一起。我想我们不妨先聊一聊你的背景，嗯，也算是把你放到我们接下来要谈论的这些时刻里——这是一个奇特的技术与社会的演化时刻，或者说我们正处在一个革命性的时刻。嗯，所以我很想这样开始：跟我们讲讲陶哲轩这个人吧。>> 好的。嗯，我 70 年代出生在澳大利亚。嗯，我父母来自中国，但我是在澳大利亚长大的。我相当西化。嗯，其实我记得小时候看了很多美国电视节目，所以我的口音尤其是这种澳大利亚和，呃，美国口音的奇怪混合。所以，呃，我一直很喜欢数学，一直很喜欢数字。嗯，我很小的时候就参加那些数学竞赛。

陶哲轩1975年生于澳大利亚阿德莱德，父母是来自香港的移民。他自称口音是澳美混合，源于童年大量观看美国电视节目。

2:34

I was tested for giftedness and I skipped actually five grades. and so I had a very accelerated education. my parents had to negotiate a lot with the headmaster of the school and the local heads of department at the local university. ended up graduating from my local university at what age 16 or something. and started graduate school at Princeton. and then after I got my PhD at Princeton I ended up at UCLA first as a postoc and then they promoted me to a full or first associate professor and then full professor. so I've been at UCLA for 30 odd years. u really like it here.

嗯，我接受过，呃，天赋测试，实际上我跳了五级。嗯，所以我的教育进程非常快。嗯，我父母不得不和学校的校长以及当地大学的，呃，系主任们进行了很多协商。嗯，最后我，嗯，从本地的大学毕业，那时候多大来着，呃，16 岁左右吧。嗯，然后开始在普林斯顿读研究生。嗯，在普林斯顿拿到博士学位之后，嗯，我最终去了 UCLA，呃，先是做博士后，嗯，呃，然后他们把我提为正教授——不，先是，嗯，副教授，然后才是正教授。呃，所以我在 UCLA 已经待了三十多年了。嗯，非常喜欢这里。

陶的教育速度极罕见：跳五级，16岁本科毕业（南澳弗林德斯大学），21岁获普林斯顿博士学位，24岁成为UCLA史上最年轻的正教授之一。

giftedness /ˈgɪftɪdnəs/ *n.*
（智力）天赋、资优

3:20

So my background I've traditionally done very pure math mostly. so I study patterns and numbers. I solve various wave equations which are related to physics but I don't sort of directly do the physical applications myself. although occasionally some of the things I do have ended up having practical implication. I did a project here at the math institute at UCLA on a puzzle involving to me just manipulating matrices and solving linear equations but it ended up being very useful for things like speeding up MRI scans. so the latest generation MRI machines are 10 times faster at performing a high quality MRI scan than they were in the past because they implemented the algorithms that we helped develop. so more recently I've gotten interested in new ways to do mathematics to incorporate all these emerging technologies AI also formal proof verification and also collaboration platforms that have been used successfully to develop say open source software. I think they can also be

嗯，说到我的背景，我一直以来做的基本上都是非常纯粹的数学。呃，所以我研究的是模式和数字。嗯，我解各种波动……这些方程和物理有关，但我自己并不太直接去做物理应用。嗯，不过偶尔我做的一些东西最后确实产生了实际影响。我在这里，在 UCLA 的数学研究所做过一个项目，是一个在我看来只是摆弄矩阵、解线性方程组的谜题，但它最后被证明非常有用，比如加快 MRI（核磁共振）扫描。嗯，所以最新一代的 MRI 机器做一次高质量扫描比过去快了 10 倍，因为它们采用了我们参与开发的算法。嗯，呃，最近我对做数学的新方式产生了兴趣，就是把这些新兴技术都融合进来——AI、形式化证明验证，还有那些已经被成功用来开发开源软件的协作平台。呃，我觉得它们也可以

此处指压缩感知（compressed sensing）：陶与Emmanuel Candès等人约2006年建立的理论，可用远少于传统要求的采样重建信号，后用于将MRI扫描提速约10倍——纯数学意外落地的经典案例。

4:22

Used to develop collaborative mathematics. I do believe that mathematics can become much more broader and relevant activity than it has in the past. A lot of research mathematics in the past was basically only available to math PhDs because even to even understand the problems we work on often required a lot of technical background. but with these new toolings and new tools and technologies we can we can broaden the pool of people who can actually contribute to math projects. I've started several crowdsourced math projects which have already been quite fun and successful.

用来发展协作式数学。嗯，我确实相信，数学可以变成一项比过去广泛得多、也更贴近现实的活动。过去很多数学研究基本上只有数学博士才接触得到，因为哪怕只是要理解我们研究的问题，往往就需要大量的技术背景。嗯，但有了这些新的工具链、新工具和新技术，我们就能扩大真正能为数学项目做贡献的人群。我发起了好几个众包数学项目，已经相当有趣，也相当成功。

「形式化证明验证」指用Lean等软件让机器逐步检查证明的正确性；陶近年发起的众包数学项目正是结合AI、形式化验证与开源式协作平台的尝试。

crowdsourced /ˈkraʊdsɔːrst/
adj.
众包的（向大众公开征集贡献的）

4:55

>> And I'd love to get into that the idea of collaborative math. But before we go there, skipping five grades at a very young age, how was that how was the social adjustment to that because I have I have I have a cousin who also started college at about 13 and we found that was really difficult for him. >> Right. Right. So well what worked for me so we had a very complicated arrangement with the local high school and primary school and the local university that I would take some classes in my regular year. So for example physical education I was not accelerated in physical education. I would take classes like in my humanities English and French and so forth I would take at my regular year. but physics and math classes I would accelerate. It would mean that when I was in primary school I would my mother would actually have to drive me to a local high school to take some classes and come back and I the scheduling was so

>> 我很想聊聊协作式数学这个想法。不过在此之前，嗯，在很小的年纪就跳了五个年级，那种感觉如何？嗯，在社交适应上怎么样？因为我有个表亲也是大概 13 岁就上了大学，我们发现那对他来说真的很难。>> 对，对。嗯，对我管用的方式是——我们跟当地的高中、小学以及当地的大学有一个非常复杂的安排：有些课我还是在自己原来的年级上。比如说体育，我在体育上没有跳级。像人文类的课程，嗯，英语、法语之类的，我都在自己原来的年级上。嗯，但物理和数学课我就跳级。这意味着我上小学的时候，我妈妈得开车送我去当地一所高中上几节课，然后再接我回来。那个课表安排太复杂了，还有成绩怎么评定。嗯，等我上高中的时候，

> 陶的答案是「分科跳级」：体育、英语、法语等留在原年级，数理课程加速——既满足智力需求又保留同龄社交，是一种折中安排。

5:56

Complicated and how to do the grading. and when I was in high school I would take some classes in the local university. So maybe what one thing of what's my favorite is that this was back in the 80s 90s there weren't that many sort of structural programs for gifted education. everyone was kind of inventing things on the fly. but one upside to that was that this very complicated schedule was just approved. like there weren't as many rules in place. and this improvisational thing worked for me. I think it didn't scale. I mean, you know, it's a so I mean I still had people my own age I interact with quite often. and this was back in a period where you could, you know, if you wanted to go play with someone, you just, you know, either pour them up or knock on the door, you know, [clears throat] you didn't have to sort of schedule things on social media or anything. so I did have a social life.

我会去当地的大学上一些课。所以也许我最喜欢的一点是，那时候是八九十年代，嗯，当时还没有那么多针对天才教育的成体系的项目，大家基本上都是临时想办法。呃，但这也有一个好处，就是这么复杂的课表居然就直接批准了。呃，比如说，当时没有那么多条条框框。嗯，这种即兴的做法对我管用。嗯，我觉得它没法推广。我是说，你知道，所以……我还是有很多同龄人经常来往。嗯，而且那还是这样一个年代：你要是想去找谁玩，你就直接，嗯，给他们打个电话，或者去敲门，你知道，[清嗓子] 你不用在社交媒体上约时间什么的。嗯，所以我确实有社交生活。

反直觉之处：八九十年代天才教育缺乏成体系项目、规则少，反而让这种高度定制的课表得以批准。陶明确承认这种即兴安排「无法规模化」。

on the fly *phr.*
临时地、边做边想地

improvisational /ɪmˌprɑːvəˈzeɪʃənl/ *adj.*
即兴的、随机应变的

scale /skeɪl/ *v.*
可规模化推广（it didn't scale 无法复制推广）

6:48

>> One thing is that because I finished high school four or five years earlier than other kids, I did miss sort of the teenage type, you know, it's like for example, I was very sad. I missed the high school social. But when I went to graduate school actually in Princeton I socialized a lot with undergraduates and I kind of interacted you know I joined film clubs and a bridge club and things like that. and so I think I did get roughly all the same social experiences that most people get just in a kind of a jumbled order.

>> 有一点是，因为我比其他孩子早四五年读完高中，我确实错过了嗯，那种青少年阶段的东西。比如说，我当时很难过，我错过了高中的舞会。但是呃，我去读研究生的时候，其实在普林斯顿，我跟本科生社交挺多的，我也算是参与了不少，你知道，我加入了电影社团，还有桥牌社之类的。嗯，所以我觉得我大致还是获得了大多数人都会有的那些社交体验，只是顺序有点乱。

陶承认错过了高中舞会等青少年体验，但读研时在普林斯顿与本科生一起加入电影社、桥牌社补上——「顺序打乱但总量相当」，回应了对神童社交缺失的普遍担忧。

jumbled /ˈdʒʌmbld/ *adj.*
杂乱的、顺序打乱的

03 为何痴迷数学：抽象与解谜

7:21

>> Different order. Yeah. >> so did you know at a very young age that what you wanted to do was mathematics? You were going to be a mathematician? Yeah, as long as I can remember, I've always liked math adjacent things. So, like solving logic puzzles, card games or any game really, computer games, board games, I like things with problems with puzzles or problems with very definite true or false answers. so, this correct, this is incorrect. And I liked the problem solving process.

>> 顺序不一样。是的。>> 嗯，那你是不是很小就知道自己想做的是数学？知道自己会成为数学家？是的，从我记事起，我就一直喜欢跟数学沾边的东西。比如说，解逻辑谜题、玩纸牌游戏，其实任何游戏都行，电脑游戏、棋盘游戏。我喜欢那种有谜题、或者有非常明确的对错答案的问题。嗯，就是这个对、这个错。而且我喜欢解决问题的那个过程。

对「有明确对错答案的问题」的偏好是贯穿陶职业选择的线索：逻辑谜题、棋牌、电脑游戏皆属此类，与他对人文开放式问题的不适形成对照。

7:50

I struggled a lot as a kid with humanities because the questions are often very open-ended and I could I couldn't quite understand what was being asked. I remember one year in English class they were asked to write about what we did over the summer break or just write about your home. And I didn't know how to take that. I think I just listed all the rooms in our house and what was in them. like I took it very literally. so yeah if I had to do it again I think I can do something better now but yeah I did have some trouble with sort of anything which wasn't extremely precise.

我小时候在人文学科上很吃力，因为那些问题往往非常开放，嗯，我不太能理解人家到底在问什么。嗯，我记得有一年英语课，老师让我们写暑假做了什么，呃，或者就写写你的家。我不知道该怎么理解这个题目。我记得我就把我们家所有房间列了一遍，还有每个房间里有什么。呃，就是我理解得非常字面。嗯，所以是的，呃，如果让我重来一次，我想现在能写得好一点，但呃，是的，我确实对任何不那么精确的东西都有点犯难。

「写写你的家」被幼年的陶字面化为逐间列出房间和物品——具体展示他对开放式问题的困惑，也侧面说明数学的精确性为何吸引他。

open-ended /ˌoʊpən ˈendɪd/
adj.
开放式的、无固定答案的

8:26

So math very much resonated with me. [snorts] I do have memories of you know when I was six or seven like being restless my parents would give me a math workbook and I'll just do the sums. I actually liked doing the me the arithmetic. and I remember in math classes in primary school they had a you had like 5 10 minutes of mental arithmetic where you had to sort of as quickly as possible you know what is what is 12 plus 25 or something and I actually like doing that you know and I enjoyed math competitions >> but sometimes that grows into you know becomes physics or it becomes you know engineering or it becomes like so sort of like applied and you're still doing of course lots of math. Was there a point in time where it was really like I don't know just the bliss of you know solving or a proof or something that was there one moment in time you're like this is really what I want to do for the rest of my life. I like abstraction, you know. So the

嗯，所以数学非常能引起我的共鸣。嗯 [笑出声] 我确实记得，六七岁的时候，我坐不住，我爸妈就会给我一本数学练习册，我就在那儿做算术题。我其实挺喜欢做算术的。嗯，而且我记得小学的数学课上有那么五到十分钟的口算，就是你得尽快说出，你知道，12 加 25 等于多少之类的，我其实挺喜欢做那个的，嗯，我也很喜欢数学竞赛。 >> 但有时候这种兴趣会长成，你知道，物理，或者工程，或者变得比较偏应用，当然你还是会做很多数学。有没有某个时刻，真的就是，我说不好，就是那种解出题目、或者做出一个证明的那种极乐感，有没有那么一个瞬间让你觉得，这就是我这辈子真正想做的事？我喜欢抽象，你知道。嗯，

restless /ˈrestləs/ *adj.*
坐立不安的、闲不住的

mental arithmetic *phr.*
心算、口算

bliss /blɪs/ *n.*
极乐、至福

9:24

The I like taking a problem and removing sort of all the irrelevant aspects to so there just like you know this is X Y and Z and they do this and playing with sort of very simplified what we call toy models you know so which are don't necessarily approximate reality but are very instructive and so I liked working on that end and in fact I the fact that math actually had impact on the real world that actually didn't interest me for a long time. I mean now it does. but I liked the abstract puzzle solving. you know the same way that people like solving cross word puzzles or maybe being good at solving a Rubik's cube or something just an intellectual challenge. I enjoyed my parents did worry you know they thought maybe that a more you know doing something more physics or engineering based might be you know maybe more employable or something. oh that was the other thing like no one had any clue what a mathematician did or even whether ma

我喜欢把一个问题里所有无关的部分都剥掉，剩下就是，你知道，这是X、Y、Z，它们做这些事，然后去摆弄那些非常简化的、我们称之为“玩具模型”的东西，嗯，你知道，它们不一定逼近现实，但很有启发性。嗯，所以我喜欢在那一端做事。事实上，数学真的对现实世界有影响这件事，在很长一段时间里其实并不吸引我。嗯，我是说现在它吸引我了。嗯，但我喜欢的是那种抽象的解谜。嗯，你知道，就像有些人喜欢解填字游戏，或者擅长复原魔方一样，纯粹是一种智力挑战。嗯，我很享受。嗯，我父母确实担心过，他们觉得也许做点更偏物理或者工程的东西，也许，你知道，更好找工作什么的。嗯，噢，还有一点就是，当时没有人搞得清数学家到底是做什么的，甚至

toy model（玩具模型）是理论研究常用方法：剥除无关细节、只留关键结构，不求逼近现实但极具启发性。注意他坦言「数学有实际影响」这点在很长时间里并不吸引他。

toy models *phr.*
玩具模型（高度简化、用于获得洞察的理论模型）

instructive /ɪnˈstrʌktɪv/ *adj.*
有启发性的、有教益的

10:22

Mathematics was a career. I remember people ask me what I wanted to do when I was growing up and I said well maybe a shopkeeper because I could I could balance the books into inventory. I mean [laughter] I mean I had the vague idea that there were professors of mathematics but I had this vision idea in my head that maybe there was there was some secret committee of senior mathematicians who would hand out problems for people to solve you know just of just like homework but at a much higher level. and I remember at some point learning that research mathematicians we select our own problems and we follow our own intellectual curiosity. I mean whether other people are interested in what you do is another question but the idea that this it's not centralized and you just sort of pursue what you think is interesting that was a revelation to me and that you can even have a career out of it >> that it's just a like a voyage of discovery that you get to self-direct.

数学算不算一种职业。嗯，我记得小时候有人问我长大想做什么，呃，我说，也许当个店主吧，因为我能算账、管库存。我是说，嗯 [笑声] 呃，我当时模模糊糊知道有数学教授这种东西，但嗯，我脑子里有个想象，觉得也许有某个由资深数学家组成的秘密委员会，他们会把题目发下来让大家解，你知道，就像作业一样，只不过层次高得多。嗯，而且我记得某个时候我才知道，研究数学家是自己选题的，嗯，我们是跟着自己的求知欲走。当然，别人对你做的东西有没有兴趣，那是另一回事，但呃，呃，这件事不是中心化的、你就去追求你觉得有意思的东西——这个想法对我来说是个启示，而且居然还能靠它谋生。 >> 就像一场你可以自己掌舵的探索之旅。

童年想象「资深数学家秘密委员会发题」与现实形成反差：研究数学家自己选题、跟随求知欲。科研的去中心化与自主性对他是一个「启示」。

balance the books *phr.*
结账、使账目平衡

revelation /ˌrevəˈleɪʃn/ *n.*
令人恍然大悟的发现；启示

04 数学从单干走向协作

11:18

>> Yeah. I mean it's part of a community. I mean if you if you only do things that come that you like and no one else cares about then you know no one cites your work no one invites you to give talks and it and yeah at some point you'll find trouble you know getting jobs or promotions whatever. so it is it's both decentralized but there is a community you know so you go to conferences you partic you find out what other mathematicians are doing what they find are interesting and every so often you see a match like there's a problem that some other mathematician is struggling with but you happen to know at all that is exactly what they need or very close to and you start talking and hopefully you find some way to collaborate or vice versa I'm stuck but because I heard somebody talk about some related problem I can go to them and ask for help. and you know we have built up a culture of small collaborations in

>> 是的。我是说，这也是一个共同体的一部分。我是说，如果你只做你自己喜欢、而别人都不在乎的东西，那你知道，没人引用你的工作，没人请你去做报告，嗯，呃，是的，到某个时候你会发现，你知道，找工作、评职称之类的会有麻烦。嗯，所以它既是去中心化的，但确实存在一个共同体，你知道，你去开会，你参与，你了解其他数学家在做什么，他们觉得什么有意思。呃，时不时你会碰到一个契合点，比如某个数学家正为一个问题发愁，而你恰好知道的某个东西正是他们需要的，或者非常接近，然后你们就开始聊，然后，希望能找到某种合作的方式；反过来也一样：我卡住了，但因为我听某人讲过某个相关的问题，我就可以去找他们，呃，向他们求助。嗯，而且，你知道，我们已经建立起一种小规模合作的文化。在过去几个世纪里，数学是一件非常个人的事。呃，人们把自己独门的数学

数学共同体的运转机制：会议和报告构成「匹配市场」——你掌握的工具可能正是他人卡壳处需要的。选题自主与共同体评价（引用、邀请报告）并存。

vice versa /ˌvaɪs ˈvɜːrsə/ *adv.* 反之亦然

12:13

Centuries past math was a very individual affair. people jealously guarded their special mathematical tricks. They didn't want to be scooped by other people. But over time you know we had journals. We had we began we began to create this culture that it's okay to collaborate and then eventually was encouraged to collaborate and that you should share your work as early as possible. yeah, you get more impact and more influence if you if you if you actually share even incomplete results than if you only if you wait too long to only just sort of release your final definitive work. so you know the trend in math during my lifetime I've seen it open up and at least we now collaborate in groups of two or three. I think we still lag behind the other sciences who are beginning to do really large collaborations 50 100 people the I think the Higs boson I think 5,000 people on the on that paper.

技巧捂得很紧，他们不想被别人抢先。但随着时间推移，嗯，你知道，我们有了期刊，我们开始慢慢形成这样一种文化：合作是可以的，后来甚至是被鼓励的，呃，要去合作，而且你应该尽早分享你的工作。呃，是的，如果你真的把哪怕不完整的结果分享出来，你会获得更多的影响力，比你等太久、只发布最终定稿的成果要好。嗯，所以，你知道，在我这一生中数学的趋势，我看到它变得开放了，至少我们现在会两三个人一组合作。嗯，我觉得我们还是落后于其他科学，它们已经开始做真正大规模的合作，五十人、一百人。我记得希格斯玻色子那篇论文好像有 5000 个作者。

历史上数学家确曾保密成果，如16世纪塔尔塔利亚与卡尔达诺围绕三次方程解法的著名争端。希格斯玻色子论文指2015年ATLAS与CMS联合论文，作者5154人，创科学论文作者数纪录。

jealously guarded *phr.*
严密守护的、秘不外传的

scooped /skuːpt/ *v.*
被抢先发表（be scooped 成果被人捷足先登）

definitive /dɪˈfɪnətɪv/ *adj.*
最终的、定论性的

13:10

So you know there are big science projects in other fields. we're only just beginning to dip our toe into big mathematics. Yeah. Where we get hundreds of people who may not know each other to work together. >> so this is a change that you saw sort of the discipline go through in your lifetime like it was much more isolated single then it moved into more collaborative work. Was that a change you welcomed? Were you excited about that? >> Yeah, very much. and it's something which I didn't appreciate you know I mean when I grew up reading about mathematics you know the we have kind of a folk history of sort of the heroes of mathematics so we have some legendary you know Gaus and Oiler and so forth and there were always individuals u usually men okay and you know and sort of the archetype was just some sort of tortured genius like no one no one knew what they were doing and then suddenly they shock all the world with their amazing discoveries and

所以你知道，其他领域有大科学项目。嗯，我们才刚刚开始试水“大数学”。是的，就是让上百个互相可能都不认识的人一起工作。嗯 >> 所以这是你在自己一生中看到这个学科经历的一种变化：以前更孤立、单打独斗，后来转向了更多的协作。这个变化是你欢迎的吗？你对此感到兴奋吗？ >> 是的，非常欢迎。嗯，而且这也是我以前没有体会到的。我是说，嗯，我小时候读数学方面的书，你知道，呃，我们有一套关于数学英雄的民间史，我们有一些传奇人物，嗯，你知道，高斯、欧拉等等，而且总是一些个人，通常是男性，好吧，嗯，呃，你知道，那种原型就是某种备受折磨的天才：没人知道他们在做什么，然后突然之间，他们用惊人的发现震惊了整个世界。所以这大概，嗯，是的，我当时

「大数学」（big math）是本期标题概念：类比物理学等领域的「大科学」项目，让数百个彼此不识的人协作解题。陶指出数学在协作规模上仍落后于其他学科。

dip our toe into *phr.*
初步尝试、试水

archetype /ˈɑːrkɪtaɪp/ *n.*
原型、典型形象

tortured genius *phr.*
备受折磨的天才（文化刻板形象）

14:08

And so this was I guess yeah so I was so sort of steeped in the history of what you might call the romantic era of mathematics where there was sort of individual heroes sort of exploring new worlds but math is a much more mature subject now where often we work in quite mature fields where there's a lot of literature it's not about people individually creating genius ideas out of out of nothing but you know understanding what other people did and putting them together in a way and work and finding ways to connect math to the other sciences and even the humanities or industry or to things that the public care about.

很深地浸泡在你可以称之为数学“浪漫主义时代”的历史里，那时候是个人英雄在探索新世界。嗯，但数学现在是一门成熟得多的学科了，嗯，我们常常是在相当成熟的领域里工作，那里有大量的文献。嗯，它不再是某个人凭空创造出天才想法，而是你知道，理解别人做过什么，把它们以某种方式拼在一起，然后，嗯，并且找到办法把数学和其他科学、甚至人文学科、或者产业界、或者大众关心的事情连接起来。

「浪漫主义时代」的个人英雄叙事（高斯、欧拉式孤独天才）与当代现实对照：如今的突破更多来自理解并组合前人工作、连接其他学科与产业，而非凭空创造。

steeped in *phr.*
沉浸于、深受…熏陶

14:46

>> And so your collaborations aren't always just with mathematicians. They can be with people from other disciplines. >> Yeah. Yeah. So this the MRI research I mentioned. Yeah. So that was with a statistician and electrical engineer. So still mostly scientists. so the crowdsource projects I run now you which have about the size 20 to 50 people. I actually I've not met most of the participants. some are ma professional mathematicians, some are students, some are from adjacent areas like computer science. some I think were students of mathematics. They enjoyed mathematics but then they went to industry like maybe work for a tech company or something but they still wanted to contribute to math as a hobby. and they have the background.

>> 所以你的合作也不总是只跟数学家。也可以是跟其他学科的人。>> 是的，是的。就像我刚提到的 MRI 研究，是的，那是跟一位统计学家和一位电气工程师合作的。所以呃，还是大多是科学家。嗯，至于我现在做的众包项目，规模大概是 20 到 50 人。嗯，其实大部分参与者我都没见过。嗯，有些是职业数学家，有些是学生，有些来自相邻领域，比如计算机科学。嗯，我想有些人以前是学数学的，他们喜欢数学，但后来去了产业界，比如去科技公司上班之类的，但他们还是想把为数学做贡献当成一种业余爱好。呃，而且他们有那个背景。

众包项目参与者画像：职业数学家、学生、计算机科学等相邻领域者，以及转入业界后把数学当业余爱好的前数学学生——门槛降低带来的人才回流。

05 格林—陶定理与素数之谜

15:25

And we've had contributions you know. So the projects we have sometimes they have some say visualization component. So we're not just creating some mathematical data but we want some nice way to visualize it. and we've had people offer with background in like you know user interfaces or graphics design sort of help with that. so you know when you when you open up a project make it crowdsourced and you it's very multifaceted. there are new types of people who can come in and contribute. You know they may not know the technical side of the project but they can help with many of the other aspects. I don't know if you've called math a process of discovery or creation, but you had a particular breakthrough around prime numbers. Could you tell us a little bit about what that breakthrough was? Of course, in layman's terms, >> right? yes. So, maybe that's my best known result is something called the green towel theorem, which I guess I

嗯，我们也确实收到过一些贡献，你知道。嗯，我们的项目有时候会有，呃，可以说是可视化的部分。就是我们不只是产生一些数学数据，我们还想用某种好的方式把它可视化出来。嗯，于是就有一些有用户界面或者平面设计背景的人主动来帮忙做这些。嗯，所以你知道，当你把一个项目开放出来、做成众包，它就变得非常多面。嗯，就会有新类型的人能进来做贡献。你知道，他们可能不懂项目的技术层面，但呃，他们能在其他很多方面帮上忙。 我不知道你会把数学称为一个发现的过程还是创造的过程，不过你在素数方面有过一个特别的突破。能稍微讲讲那个突破是什么吗？当然，用外行能听懂的话讲。>> 好吗？呃，好的。嗯，也许我最有名的成果是所谓的格林—陶定理，我想我

众包的多面性：项目需要可视化、界面设计等非数学技能，让不懂技术核心的人也能贡献——呼应前文「扩大能参与数学的人群」的主张。

layman's terms *phr.*
外行能懂的话（in layman's terms 用通俗的话说）

multifaceted /ˌmʌlti'fæsɪtɪd/ *adj.*
多方面的、多元的

16:20

Proved with Ben Green in 2004. so, I've always been fascinated with number theory and prime numbers. And prime numbers are numbers that are not divisible by any smaller number but except for one. so 2 3 5 7 they're one of the oldest objects that we studied. The ancient Greeks studied them. But there's so much we don't know about the prime numbers. because when you actually write them out they don't seem to obey any discernable pattern. Sometimes numbers are close to each other, sometimes they're far apart.

与本·格林在2004年证明的。嗯，所以，我一直对数论和素数很着迷。而且素数是指除了1以外，不能被任何更小的数整除的数。嗯，所以2、3、5、7，它们是我们研究过的最古老的对象之一。古希腊人就研究过它们。但关于素数还有太多我们不知道的东西。因为当你把它们真正写出来时，它们似乎不遵循任何可辨识的规律。有时候数字彼此靠得很近，有时候又相隔很远。

素数：除1以外不能被更小的数整除的数（2、3、5、7...）。古希腊人已开始研究，欧几里得证明了素数有无穷多个；素数分布看似毫无规律，是数论的核心难题。

divisible /dɪˈvɪzəbl/ *adj.*
可整除的

discernable /dɪˈsɜːrnəbl/ *adj.*
可辨别的、可察觉的（规范拼写 discernible）

16:49

There's an unsolved question which is 300 years old called the twin prime conjecture. So, prime numbers that are distance two apart, like 11 and 13. They're called twin primes. We believe that there are there are there's an unbounded an infinite number of twin primes. that we'll never run out of twin primes. We found millions of them, but will we ever run out? We don't we don't believe so. but we can't prove it. And that's kind of annoying despite centuries of progress in number theory. So, we still can't solve that. I would love to. That's one of my favorite problems. but what Ben and I were able to show was that we could find within the primes, we can't find twins, but we can find a different type of pattern called arithmetic progression. so primes that are equally spaced like 3, five and seven have an equal spacing of two. So you can find three or four primes in a row that are equally spaced. and I think before our theorem, the world record is like 21 or 22. but

嗯，有一个已经存在了300年的未解问题，叫做孪生素数猜想。就是说，相距为2的素数，比如11和13。它们被称为孪生素数。我们相信孪生素数有无穷多个、没有上界，也就是说我们永远不会把孪生素数用完。我们已经找到了数百万对，但我们会不会有一天用完呢？我们认为不会。嗯，但我们证明不了。这就有点让人恼火，尽管数论已经有几个世纪的进展。我们还是解决不了这个问题。我很想解决它。这是我最喜欢的问题之一。嗯，但本和我能够证明的是，嗯，我们可以在素数中找到——我们找不到孪生素数，但我们能找到另一种模式，叫做等差数列。嗯，就是间距相等的素数，比如3、5、7，它们的间距都是2。所以你可以找到连续三个或四个间距相等的素数。呃，我想在我们的定理之前，世界纪录大概是21或22个。嗯，但是呃，但我们设法证明了存在

孪生素数猜想：相差2的素数对（如11和13）是否无穷多，约300年未决。2013年张益唐证明素数间隙有界（7000万以内）是该方向最重大进展，但原猜想仍未解决。

conjecture /kənˈdʒektʃər/ *n.*
猜想（未被证明的数学命题）

unbounded /ʌnˈbaʊndɪd/ *adj.*
无界的、无限的

arithmetic progression *phr.*
等差数列

17:43

We managed to find an unlimited number of we you could find prime progressions that are of any length. and the way we did it was that so we didn't know whether the primes were randomly distributed or very structured had secret patterns that we weren't aware of. but we found a proof technique which we now call the dichotomy between structure and randomness that either the primes have a lot of structure or they're very random. But in either case, we could prove that the these arithmetic progressions existed. and so regardless of whether what the primes did, they were forced to contain these progressions unless that's how we solve that problem. And this technique has since been sort of applied to other problems. And we've been we since know actually the primes are more randomly distributed than structured. so yeah this particular works sort of kicked off you know two decades of follow-up work >> and you still find those regressions

无穷多个，嗯，你可以找到任意长度的素数等差数列。嗯，我们的做法是这样的，我们当时并不知道素数是随机分布的，还是有着某种我们尚未察觉的隐秘规律、非常有结构性。呃，但我们找到了一种证明技巧，我们现在称之为「结构与随机性的二分法」——要么素数具有很多结构，要么它们非常随机。但无论是哪种情况，我们都能证明这些等差数列是存在的。嗯，所以不管素数表现如何，它们都必然包含这些数列——除非，这就是我们解决那个问题的方式。而这个技巧后来也被应用到了其他问题上。而且我们现在其实已经知道，素数更接近随机分布，而不是有结构的。嗯，所以是的，这项具体的工作可以说开启了长达二十年的后续研究。>> 而且你仍然能找到那些数列，因为我知道最近人们

格林—陶定理（2004）的证明策略「结构与随机性二分法」：不必知道素数偏结构还是偏随机，两种情形都能推出任意长等差数列存在——这种「无论如何都赢」的论证框架影响了此后二十年研究。

dichotomy /daɪˈkɑːtəmi/ *n.*
二分法、两分对立

18:38

That because I know recently they're using computers to find huge prime numbers like 56 milliondigit prime numbers or something like this like really so you'll even find those progressions at really large scales >> yeah theoretically yeah I mean >> we don't really give a formula to locate exactly where they are roughly speaking what we do is that we put all primes in a big box and we kind of weigh how many progressions there are, you know? So, so if you have a big box and you don't know what's in it, but you weigh it and it's heavy, that tells you there's something in it, but it doesn't know what it is or where in the box this is. so, so we had kind of this indirect way of detecting what the how many progressions were was were stuck inside the primes. but I couldn't tell you where they were exactly, >> right? yeah but yeah but it's part of a of a you know we use primes so prime number theory used to be this one of the most abstract areas of

在用计算机寻找巨大的素数，比如5600万位的素数之类的，真的非常非常大——所以你在非常非常大的尺度上也能找到那些数列？>> 是的，理论上是的。我是说 >> 我们并没有给出一个公式来精确定位它们在哪里。嗯，粗略地说，我们做的是把所有素数放进一个大箱子里，然后我们大致「称一称」里面有多少个等差数列，你知道吗？所以，如果你有一个大箱子，你不知道里面装了什么，但你一称，发现它很重，嗯，那就告诉你里面有东西，嗯，但你不知道那是什么，也不知道它在箱子的哪个位置。呃，所以我们用的是这种间接的方式来探测，呃，嗯，素数里面藏着多少个等差数列。呃，但我没法告诉你它们究竟在哪里。>> 对。嗯，是的，但这也是——你知道，我们用素数，嗯，素数理论过去曾是数学中最抽象的领域之一。嗯，20世纪初有一位数学家G.H.哈代，他甚至夸口说自己是个

「称箱子」比喻解释非构造性证明：能证明等差数列存在（箱子很重），却给不出定位公式（不知东西在哪）。大素数搜索指GIMPS等分布式计算项目，已知最大素数超4100万位。

19:33

Mathematics. there was this mathematician of the early 20th century GH Hardy who even boasted he was a pacifist. He abhored World War I. and he boasted that he worked in this area called number theory where which could not possibly have any reward application and you know cannot be used for any bad purpose. But actually the properties of prime numbers are instrumental in all our cryptographic algorithms now or not all of them but most of them. if you want to encrypt data over the internet like say your credit card number you want to do some secure transaction it's all your data is shuffled using the properties of prime numbers as it turns out. and this basically this belief which has been reinforced over many decades that prime numbers have very good randomizing properties that there's certain operations you can do prime numbers that make things that mix things very well and can kind of anonymize all your data. and the results I do are kind of adding to that

和平主义者。他厌恶第一次世界大战。嗯，他还夸口说他从事的这个领域叫数论，而数论不可能有任何实际应用，你知道，也不可能被用于任何邪恶的目的。但实际上，素数的性质如今在我们所有的密码算法中都至关重要——不是全部，但大多数都是。嗯，如果你想在互联网上加密数据，比如说你的信用卡号，你想进行某种安全交易，嗯，结果就是你所有的数据都是利用素数的性质来打乱的。嗯，而且基本上，这个经过几十年不断强化的信念是：素数具有非常好的随机化性质，嗯，你可以对素数做某些运算，让东西混合得非常充分，呃，从而在某种程度上把你的数据匿名化。嗯，而我做的这些结果算是在加强

> G.H.哈代在《一个数学家的辩白》（1940）中自豪于数论「无用无害」；讽刺的是素数性质如今是RSA等公钥加密的基石，网上信用卡交易全依赖它——「无用之用」的最著名例证。

pacifist /ˈpæsɪfɪst/ *n.*
和平主义者

abhored /əbˈhɔːrd/ *v.*
憎恶、痛恨（规范拼写 abhorred）

boasted /ˈboʊstɪd/ *v.*
夸耀、自诩

cryptographic /ˌkrɪptəˈgræfɪk/ *adj.*
密码学的、加密的

instrumental /ˌɪnstrəˈmentl/ *adj.*
起关键作用的（be instrumental in）

anonymize /əˈnɑːnəmaɪz/ *v.*
使匿名化

20:27

Belief. there could be one day a surprising result that primes obey some secret pattern that we didn't expect to be to be there. and if that happens suddenly half of cryptography becomes in doubt that maybe some of our algorithms that we think are secure maybe they have a back door. U so but we've had a century of work sort of showing the opposite that the primes don't seem to have any such pattern. So far I think is the current cryptographic algorithms look pretty secure at least until quantum computers come along but that's another story >> and that's another story the I'd love to talk a little bit about what you know what is that process is math and like solving proofs or you know is it a process of discovery or is it a process of creation? It's both. there's definitely patterns out there waiting to be discovered. but the process of finding them is very human. and often you have to dig into human literature, see what other people have

这个信念。嗯，但也许有一天会出现一个令人意外的结果，表明素数遵循某种我们意想不到的隐秘规律。嗯，如果那样的话，突然之间一半的密码学就要打上问号了——也许我们以为安全的某些算法，其实存在后门。呃，但我们已经有一个世纪的研究工作在证明相反的一面，即素数似乎并不存在这样的规律。所以呃，到目前为止我认为现有的呃呃密码算法看起来相当安全，至少在量子计算机出现之前是这样，但那就是另一个话题了。>> 那是另一个话题了。嗯，我很想聊一聊，你知道，那个过程是什么样的——数学、解决证明，你知道，它是一个发现的过程，还是嗯，一个创造的过程？两者都是。嗯，确实有一些规律在那里等着被发现。嗯，但寻找它们的过程非常人性化。嗯，而且你常常得钻研人类的文献，看看还有谁

关键脆弱性：现代密码学建立在「素数无隐秘规律」这一经验信念上，一旦被推翻，半数加密算法可能存在后门。量子计算机（Shor算法可破解RSA）是另一条独立的威胁线。

back door *phr.*
（安全系统中的）后门、暗道

06 数学家的日常与试错文化

21:36

Worked on the problem. You got to you try things. you give things names and you try to systematically you try to f shape some narrative about you know so we often anthropomorphize you know. So maybe there's some equation you want to solve. You know, x plus y equals z. and to an untrained expert, you know, these are just symbols, but you know, you t say, "Oh, this is this is the good term. This is the term we want to dominate order." And this term is the error term. We want to somehow get rid of it or make it small. And we do kind of assign personalities. I mean, it's not such a touchyfey subject mathematics famously, but yeah, but everyone has their own internal language of how they understand things. It's there was a quote by I think W de Dwis that he said that when you understand mathematics you will no longer see numbers and symbols you will see meanings. so I mean mathematics actually just a language which is but it's just a very weird looking

研究过这个问题。你得去尝试各种方法。嗯，你给事物起名字，然后你试着系统地去塑造某种叙事，你知道，所以嗯，嗯，我们经常把它们拟人化，你知道。比如说，也许有个方程你想解，你知道，x加y等于z。嗯，对一个没受过训练的人来说，这些只是符号，但你知道，你会说：「哦，这是那个好的项。这是我们想让它成为主导阶的项。」而这一项是误差项。我们想设法把它去掉，或者让它变小。我们确实会赋予它们某种个性。我是说，这倒不是什么多愁善感的话题，数学向来以严谨著称，但呃嗯，是的，不过每个人都有自己内在的一套语言来理解事物。嗯，有一句话我想是呃W·迪厄多内说的，嗯，他说当你真正理解数学时，你看到的将不再是数字和符号，你看到的将是意义。嗯，所以我是说，数学其实就是一种语言，嗯，只不过它是一种看起来很奇怪的语言，但它是为

引言出自法国数学家迪厄多内：理解数学后「看到的不再是符号而是意义」。数学家给「主导项」「误差项」赋予个性、构造叙事——数学远比外界想象的更依赖直觉化的内部语言。

anthropomorphize /ˌænθrəpəˈmɔːrfaɪz/ *v.*
拟人化

22:37

Language but it's designed for precision but it is trying to capture things that we can say about the real world. you know that when you say x plus y is z, we're saying that whatever z is representing, it's made up of x and y in some way. and it's just a very precise way of saying ideas and communicating them to others. So, what does the workday of a mathematician look like? well, we teach classes. there's administrative work. So, this there's the teaching aspect of it. we mentor students and, we go to we go to conferences. then we work on problems. and sometimes, yeah, you just sit with pen and paper. You say, "I'm going to try solving it this way." And you try something and you get stuck, but you say, "Oh, but why did it get stuck?"

精确性而设计的，而且它试图捕捉我们能对现实世界所说的那些事情。你知道，当你说x加y等于z时，我们是在说，不管z代表什么，它都是由x和y以某种方式构成的。嗯，这只是一种非常精确地表达思想、并把它们传达给别人的方式。那么，数学家的工作日是什么样子的呢？呃，嗯，呃，我们要上课。呃，还有一些行政工作。所以，这其中有教学的部分。嗯，我们指导学生，还有，呃，我们会去参加会议。嗯，呃，然后我们研究问题。嗯，有时候，呃，是的，你就是坐下来拿着纸和笔。你说：“我要试试用这种方法解决它。”然后你试了一下，卡住了，但你会说：“哦，可是为什么会卡住呢？”

> 数学家的日常构成：教学、行政、指导学生、开会、纸笔攻题。注意他描述的核心循环：尝试—卡住—追问为什么卡住—发现遗漏的现象或反例—绕开它。

23:21

Oh, it's because I didn't take into account this phenomenon or there's this example that shows that this would never have worked anyway. Ah, so I need to go around that example. To me, it reminded me of u the problem solving process reminds you a little bit of playing computer games as a child. so I grew up in an era where it was not easy to look up. The internet barely existed. So if you were stuck on a computer game that you had, maybe a friend of yours who also has the same game could help you. But usually you were stuck and you just had to try the same puzzle again and try something different and you get stuck again and it would take months before you finally crack it. It was very satisfying when you finally find the correct combination or something. but you experiment. and yeah you try something it doesn't work you try something else it doesn't work. one nice thing about math which is different from many other disciplines is

哦，是因为我没有考虑到这个现象，或者有这么一个例子说明这条路本来就走不通。啊，所以我得绕开那个例子。对我来说，这让我想起，呃，那种解决问题的过程有点像小时候，嗯，玩电脑游戏。嗯，我成长的那个年代，嗯，查资料不容易。互联网几乎还不存在。所以如果，如果你在某个电脑游戏里卡住了，也许某个也有同一款游戏的朋友能帮你。但呃通常你就是卡在那儿，只能一遍遍地重试同一个谜题，呃，试点别的办法，嗯，然后又卡住，可能要花上好几个月才终于破解。当你最终找到正确的组合什么的时候，那种感觉特别满足。嗯，但你就是在做实验。嗯，然后呃呃是的，你试一种方法不行，再试另一种也不行。嗯，数学有一点很好，跟很多其他学科不一样，

前互联网时代玩游戏卡关数月、只能反复试错的类比：数学研究需要的不是灵感闪现，而是长期试错的耐心，以及从失败中提取信息的能力。

crack it *phr.*
破解、攻克（难题）

24:10

That failure is very cheap you know. So like if you are an engineer and you're asked to board a bridge and the bridge collapses you're in trouble. Okay. If you're a surgeon and you're asked to perform heart surgery and you cut the wrong thing you're in trouble. Okay. But yeah, if you're a mathematician and you ask to solve this equation and your solution doesn't work, you just start over like it there isn't this cost. And this is something we have to teach our students because our students often in other classes they are told you cannot fail. This is important. It is it if you screw up you know people will get will suffer. but in math is one of the few places where it's okay to try stupid things and you fail but you learn from them and you try again.

那就是呃失败的代价非常低，你知道吧。比如说，如果你，嗯，是个工程师，人家让你造一座桥，结果桥塌了，你就有麻烦了。好吧。如果你是外科医生，人家让你做心脏手术，你，你，你切错了地方，你就有麻烦了。好吧。但是，如果你是个数学家，人家让你解这个方程，你的解法不管用，你重新来过就行了，就，嗯，没有那种代价。这也是我们必须教给学生的东西，因为呃我们的学生在别的课上常常被告知，你不能失败。这很重要。呃，如果你搞砸了，你知道，会有人因此受苦。呃，但在，在数学里，这是少数几个可以，可以尝试蠢办法的地方之一，你失败了，但你从中学到东西，然后你再试一次。

理解数学教育价值的关键段：与造桥、手术不同，数学中失败几乎零成本，是少数能安全尝试「蠢办法」的领域——而学生在其他课上被教育「不能失败」，需要专门纠正。

screw up *phr.*
搞砸、弄糟

24:55

It's sort of a safe place to play I guess in that way. Yeah. I mean it seems you know so necessary to go through the process of multiple failures in something like theoretical mathematics. is that like the cultural norm among mathematicians that like yeah you're supposed to continue to progress the problem banging into as many mistakes as you can until you find way forward. >> It is the cultural norm behind closed doors. so yeah when we actually publish our papers and we present them in talks and things we tend to only present our final the final thing that actually worked. it's like sort of a highly edited version of the of the process. you know it's sometimes you see these making of videos where someone did some trick shot that looks amazing and then say oh there's 100 takes of things that didn't quite work before that but somehow because of that they were able to do the thing right eventually and that was the cut they used [snorts] and so math is a

从这个意义上说，它算是一个可以安全玩耍的地方吧。是的。我是说，看起来，你知道，在理论数学这样的领域里，经历多次失败的过程是如此必要。嗯，这算是数学家之间的一种文化常态吗？就是说，你就应该不断推进问题，撞上尽可能多的错误，直到找到前进的路。>> 在关起门来的时候，这是文化常态。嗯，所以，嗯，是的，当我们真正发表论文、在演讲里展示它们的时候，我们往往只呈现最终的、真正成功的那个东西。嗯，这就像是那个过程的一个高度剪辑过的版本。嗯，你知道，呃，有时候你会看到那种幕后花絮视频，有人做了个看起来惊艳的花式投篮，然后说，哦，在那之前有一百次没投进的镜头，但不知怎么的，正因为如此他们最终才能把那一下做对，而那就是他们用的那个镜头。嗯 [笑] 数学有点像那样，也正因为如此，我们确实会有一种，呃，冒充者

「关起门来才是常态」：论文和报告只呈现成功路径，如同花式投篮视频只放成功的那一条——学术出版是对研究过程的高度剪辑版。

behind closed doors *phr.*
关起门来、私下里

25:55

Little bit like that and because of that there is kind of we do get imposter syndrome among graduate students sometimes where they read papers written by you know big got, you know, famous names and they're proving these amazing theorems and then they're working on their own theorem and they just keep failing. and they say I'll never be as good as the authors I'm reading about. But what they often are not aware of is that those same authors, they also had, you know, lots of mistakes and dead ends. They just didn't publish those. so one little byproduct actually of all these collaborative open projects that I've been running I said you know we solve these problems but we just from the nature we do things openly on the internet there's a record of all the half steps and back and forth and this didn't work but this partly works so we'll say that this part of the argument if we can find something else that can sort of match that then we can

综合症，嗯，嗯，有时候在研究生中间，他们读那些由，你知道，大人物、名家写的论文，人家在证明这些了不起的定理，然后他们自己在做自己的定理，却一直失败。嗯，他们就说，我永远不可能像我读到的那些作者那么厉害。但他们往往没意识到的是，那些同样的作者，你知道，也犯过很多错误、走过很多死胡同。他们只是没把那些发表出来。嗯，嗯，所以其实我一直在做的这些协作式开放项目，有一个小小的副产品，嗯，我是说，你知道，我们解决这些问题，但我们，嗯，就因为我们是在互联网上公开地做事，所以留下了所有那些走了一半的步骤、来来回回、这个不行但那个部分可行的记录，所以我们会说，论证的这一部分，如果我们能找到别的什么东西可以，嗯，呃，跟它对得上，嗯，那我们就能

冒充者综合征在研究生中的成因：读大师论文只见辉煌定理，不见其未发表的错误与死胡同。公开协作项目的意外副产品是完整保留试错记录，让学生看到「幕后」。

imposter syndrome *phr.*
冒充者综合征（觉得自己名不副实的心理）

dead ends *phr.*
死胡同、走不通的路

byproduct /ˈbaɪprɑːdʌkt/ *n.*
副产品、附带结果

26:50

Solve the whole thing and this kind of process which is often hidden from traditional publications was very open. and I definitely had feedback from students afterwards who were who didn't participate. They just they just watched these things unfold and they're very grateful to see some example of what happens behind the curtain. H it must be so what you just described it are generally I mean I always imagine that when you're solving these things it's sort of a cumulative process that everything you've done so far is correct and you're just trying to figure out the next part but >> it's probably not like that is it you probably need to go back you can like almost fractionalize it and break it up into pieces >> this it's a tree >> it's not linear >> no it's not linear I mean it is cumulative you are using some of what you did before some of the things are dead ends or some are partial.

解决整个问题。而这种通常在传统发表中被隐藏起来的过程，呃，是非常公开的。嗯，而且我后来确实收到过学生的反馈，嗯，是那些没有参与的学生。他们只是只是看着，嗯，这些事情展开，他们非常感激能看到一个幕后发生什么的实例。嗯，那一定，嗯，所以你刚才描述的，一般来说，我是说，我总是想象，当你在解这些东西的时候，那是一个累积的过程，你到目前为止做的一切都是对的，你只是在试图弄清楚下一部分，但 >> 实际大概不是那样的，对吧？你大概需要往回走，你可以说几乎是把它分成小块、拆开成一个个片段 >> 这，这是一棵树 >> 它不是线性的 >> 不，它不是线性的。我是说，它确实是累积的，你会用到你之前做过的一些东西。嗯，有些东西是死胡同，或者有些是部分有效的。

主持人以为证明是线性累积过程，陶纠正：它是一棵树——有死胡同、有部分有效的分支，要保留有用部分、剪掉无用部分。

cumulative /ˈkjuːmjəleɪtɪv/ *adj.*
累积的、渐增的

27:41

Yeah. Some are partially valuable and you got to keep the part that was useful and remove the part that wasn't useful. yeah. So it's like a brainstorming session where yes it's especially fun when you have many people [snorts] you know that people toss out ideas and yeah often things they don't solve the problem but sometimes you get a sense oh it somehow nudge things a little bit. It's like maybe you're trying to open a door and it's stuck. and you know, you try the handle, it doesn't work, and you try shoving it, and then you try something, and the door like shifts, but it's still stuck, but like, but there was movement, and okay, that's, you know, that's something, and how can I combine that with something else? I don't know if you ever been to these puzzle rooms. you know, they become reasonably popular. Those type of problem solving tasks, they just remind me a lot actually of the mathematical solving process. you get kind of

是的。有些是部分有价值的，你得留下有用的那部分，然后去掉没用的那部分。嗯，是的。所以它就像一场头脑风暴，嗯，是的，特别是当你有很多人的时候尤其好玩，嗯 [笑] 你知道，呃，大家抛出各种想法，是的，很多时候这些想法解决不了问题，但有时候你会有种感觉，哦，它，它，它多少把事情往前推了一点点。就好像，也许呃你想打开一扇门，但它卡住了。嗯，你知道，你试试把手，不行，你试着用力推，然后你试了点别的，那门动了一下，但还是卡着，不过，但确实有动静，好吧，那，你知道，那也算点什么，那我怎么把它和别的东西结合起来？嗯，我不知道你有没有去过那种密室逃脱。呃，你知道，它们现在挺流行的。那类解谜任务，其实让我很容易联想到数学的求解过程。你，你从各种尝试中得到一些微妙的线索，虽然没完全

「卡住的门动了一下」的比喻：微小进展本身就是信息，头脑风暴中解决不了问题的想法也可能指出推进方向——这是集体解题的价值所在。

toss out *phr.*
（随口）抛出（想法）

nudge /nʌdʒ/ *v.*
轻推；使微微推进

shoving /ˈʃʌvɪŋ/ *v.*
用力推、猛推（shove）

28:36 主持人

Subtle clues from trying things and not quite working but something happened that was that was a good sign. >> It must be really fun to have collective breakthroughs when you're working on a problem like that. My son was talking about it because he's studying mathematics at McGill and he says his favorite there's actually like a study space where pe students come together and they just somebody will be working on something and other people will come and help them or they'll do kind of teamwork kind of and he loves it. He's like that's his favorite place to study, I guess.

成功，但发生了一些事情，呃，那是个好兆头。>> 在做这样的问题时能有集体的突破，那一定非常有意思。我，我儿子就说起过这个，因为他在，嗯，在麦吉尔大学学数学，他说他最喜欢的——那儿其实有个自习空间，学生们会聚到一起，就是有人在研究什么东西，然后其他人会过来帮他，或者他们会搞那种团队合作，他特别喜欢。他说那是他最喜欢的学习地方，大概吧。

29:04 陶哲轩

>> Yeah. No, there's a social part of the brain that gets activated when you're talking to other people. and it somehow increases your math ability in weird ways to the extent where so this phenomenon called rubber ducking. >> rubber ducking. >> yeah. So it's a computer software engineering term. So sometimes there's a programmer who wants to program there's a bug in their code and they can't quite see they can't see how to how to solve it. but what works surprisingly well is you take a rubber duck. It doesn't have to be a rubber duck but traditionally is a rubber duck and you explain the problem to them. And just because you're now verbalizing and socializing so to speak with someone else or something else it you think about the problem in a different way. And then usually often halfway through explaining, oh, I see what I did wrong.

>> 是的。不，那个……大脑里有一个社交区域，在你跟别人说话的时候会被激活。嗯，而且它会以某种很奇怪的方式提升你的数学能力，甚至到了这种程度——有个现象叫做「小黄鸭调试法」。嗯 >> 小黄鸭调试法。>> 呃对。这是个计算机软件工程的术语。有时候，一个程序员想写程序，代码里有个 bug，他就是看不出来该怎么解决。嗯，但是呢，有一个办法出奇地管用：你拿一只橡皮鸭子——其实不一定非得是橡皮鸭，但传统上就是橡皮鸭——然后你把问题讲给它听。就因为你现在把它说出来了、所谓地「社交」了一下，跟别人或者别的什么东西讲了一遍，嗯，你就会用另一种方式去思考这个问题。然后通常讲到一半的时候，哦，我看出我哪里错了。

小黄鸭调试法出自《程序员修炼之道》(1999)：向橡皮鸭逐行解释代码，往往讲到一半自己就发现错误。原理是言语化调用了大脑不同的加工通路。

rubber ducking *phr.*
小黄鸭调试法（向物体讲解问题以理清思路）

verbalizing /ˈvɜːrbəlaɪzɪŋ/ *v.*
用言语表达出来（verbalize）

29:55

Yeah. And then the other thing that sort of you do get the feeling that when you're talking with somebody else who is on your wavelength and your what you say the other person instantly understands and vice versa. there is kind of a super intelligence that gets created that you can arrive at conclusions that neither one of you could arrive at separately. you know you know there's been a few you know I've had some friends who are so close that you know we can sometimes complete each other sentences and in math you can kind of do something similar when you're working on the same problem and you sort of because math is so precise you know you can be really in tune and it's a really good feeling of having that connection.

嗯，对。还有另一件事就是，你确实会有这种感觉：当你和一个跟你思路合拍的人交流时，你说的话对方立刻就懂了，反过来也一样。嗯，这时候就会产生一种「超级智能」，你们能得出一些结论，是你们任何一个人单独都得不出来的。嗯，你知道，我有几个朋友关系近到，我们有时候能接上对方没说完的话。嗯，在数学里你也能做到类似的事——当你们在做同一个问题的时候，因为数学非常精确，所以你真的可以特别默契，那种连接感是种非常好的感觉。

「超级智能」在此指默契协作的涌现效应：两个思路合拍的人能得出任何一方单独得不出的结论——为后文讨论AI作为「合作者」埋下参照。

wavelength /ˈweɪvleŋθ/ *n.*
波长；on your wavelength 与你思路合拍

in tune *phr.*
合拍、默契一致

30:36 主持人

>> It sounds like you've got a lot of different kinds of project just going back a bit a lot of different kinds of projects or things that you're solving for. Is there any particular problem you're solving for right now? Or maybe there's something that like you're constantly working on in the background like when like writing a book that somebody doesn't always have time for, but they're writing in the background. Is there some problem that fascinates you that you're kind of always working on some level?

>> 听起来你手上有很多不同类型的项目——稍微往回说一点——很多不同类型的项目或者你在解决的问题。现在有没有什么特别的问题是你正在攻克的？或者说，有没有什么是你一直在后台默默琢磨的？就像有人在写一本书，平时不见得总有时间，但一直在背景里写着那样。有没有哪个问题让你着迷，让你在某种程度上一直都在想？

07 费曼清单与「元数学」转向

31:01 陶哲轩（穿插主持人提问）

>> Yeah. So, I think Richard Feman had this advice. who was a physicist that you know you should always have this list of like 10 problems in your head that you want to have solved and then every time you learn some new idea or trick just so mentally check it against one of your 10 favorite problems and then just hope one day there'll be a match and then and then you work it out you review that and everyone gets impressed how did you ever come up with that you know so this was one of his secrets to I mean he was kind of a showman actually he liked to impress people with this you things coming out of nowhere. But this was one of his methods. So I definitely did subscribe to that kind of philosophy and actually I think I have done I think nowadays yeah I mean I'm getting a little bit older. I'm happy to have the younger generation sort of do the flashy problem solving things. U I might give them a suggestion or two. But I'm more

>> 有。嗯，我记得理查德·费曼有过这么个建议。呃，他是位物理学家，他说，你应该在脑子里始终装着一份大概 10 个问题的清单，都是你想解决的。然后每次你学到什么新想法或者新技巧，就在心里拿它跟你那 10 个最喜欢的问题挨个对一遍，然后就盼着有一天能对上号，然后嗯，然后你就把它做出来，你回头一梳理，所有人都惊呆了：你到底是怎么想到的？你知道，这算是他的秘诀之一。我是说，他其实挺有表演欲的，他喜欢用这种好像凭空冒出来的东西去震住别人。但这确实是他的方法之一。所以我确实很认同这种理念。嗯，其实我觉得我，我觉得我做到过。我觉得现在嘛，对，我是说我年纪也大了一点。我很乐意让年轻一代去做那些光鲜亮丽的解题工作。我可能会给他们一点建议，嗯，一两条。但是呃，嗯，我现在更感兴趣的是那种更「元数学」的东西，比如说，我们怎么

费曼的「10个问题」心法：脑中常备十个未解问题，每学到新技巧就逐一核对，一旦匹配便产出令人惊叹的成果。陶点破这也是费曼「表演型人格」制造惊奇感的方法。

subscribe to *phr.*
赞同、信奉（观点、理念）

flashy /ˈflæʃi/ *adj.*
炫目的、抓眼球的

showman /ˈʃoʊmən/ *n.*
有表演欲/善于制造效果的人

31:59

Interested now in sort of more meta mathematical things like how can we accelerate the entire process of mathematics but I think what I'm more interested now is so as a community how can we have better workflows and this like there's a lot of redundancy and inefficiency in the way we do mathematics nowadays in many ways we haven't changed very much from like the 19th century like we're almost pre-industrial revolution in the Hey, we do our research. Like it's like when people when they used to make like a doll or something, they'll be like one person and their apprentice, you know, just by hand carving and go and sort of making each of the pieces. and only after the industrial revolution and automation and mass production, you know, do we have these factories which can produce hundreds thousands of toy at the same time. So math is still in largely in sort of the craft guildsman era you know of individuals and their apprentices maybe groups of two or three

才能加速整个数学的进程。不过我想，呃，我现在更感兴趣的是，作为一个共同体，我们怎么才能有更好的工作流程，还有，就是，我们今天做数学的方式里有很多冗余和低效。在很多方面，我们跟 19 世纪相比并没有太大改变。嗯，我们做研究的方式几乎还停留在工业革命之前。这就像，就像以前人们做一个玩偶之类的东西，就是一个师傅带一个学徒，你知道，纯手工雕刻，一件一件地做出每个部件。嗯，只有在工业革命、自动化和大规模生产之后，才有了这些工厂，能同时生产成百上千个玩具。所以嗯，数学在很大程度上仍然处在那种手工行会的时代，你知道，就是一个个个体和他们的学徒，或者两三个人组成的小组一起做项目。嗯，但这就意味着有大量的

陶当前研究重心的自白：从解具体问题转向「元数学」——如何加速整个数学学科的进程。他把当代数学比作工业革命前的手工行会：师徒二三人的手工作坊式生产。

redundancy /rɪˈdʌndənsi/ *n.*
冗余、重复浪费

apprentice /əˈprentɪs/ *n.*
学徒

guildsman /ˈgɪldzmən/ *n.*
行会工匠、行会成员

33:00

People working on projects. but it means that there's a lot of redundancy like for example basic thing is literature search you know so one of the first things you do when you try to work on a math problem is that you look for what has been done before on the problem. and sometimes there's some relevant work which is great. sometimes there isn't but often if you don't end up writing a succeeding in writing a paper on the subject you don't record all the literature review that you did and so if you try something and you fail the next person who works on the same problem doesn't know what you did and they would try to do the same searches maybe search futilely for this literature that doesn't exist and if they knew that there was a previous attempt and if they had disclosed their failure to find something that would have been useful for the next person but because of this culture of not disclosing failures, not reporting negative results which is

冗余。嗯，比如说，一个最基本的例子就是文献检索。你知道，嗯，当你着手做一个数学问题时，首先要做的事情之一就是去找这个问题以前有人做过什么。嗯，有时候能找到一些相关的工作，那很好。呃，有时候找不到。嗯，但通常如果你最后没能就这个课题写出一篇论文，你就不会把你做过的所有文献综述记录下来。所以嗯，如果你试过某条路并且失败了，下一个做同样问题的人并不知道你做过什么，嗯，他们就会去做同样的检索，可能徒劳地去找那些根本不存在的文献。而如果他们知道之前有人尝试过，嗯，如果那个人公开过自己「没找到什么」的结果，那对下一个人是很有用的。但由于这种不公开失败、不报告负面结果的文化——这其实是个比数学更广泛的问题，在其他

> 负面结果不发表（publication bias）的具体机制：失败的尝试连文献检索记录都不留，后人只能重复同样的徒劳搜索——这是比数学更普遍的科学界通病。

futilely /ˈfjuːtəlli/ *adv.*
徒劳地、白费力地

disclosed /dɪsˈkloʊzd/ *v.*
披露、公开（disclose）

33:52

Actually a broader problem than mathematics happens in the other sciences too. that yeah there's a lot of redundant wasted effort I mean sometimes it's good to replicate these experiences but we do it too much. so I think there are some ways as collectively we can be much more efficient and make math much more useful actually for the other sciences by changing our workflows making them a bit more modern. There's so many tools out there now not just AI but even pre– AAI software and so on that the process of doing mathematics must be influenced by that right there is I mean it must in some ways become more efficient >> yeah know some things are better you know I when I was a grad student it was still very common to have secretaries type up all your handwritten papers you know and so you'd write very carefully and then you'd hand the secretary type come back and there's some typos and you have to correct them and it's a painful process Yes. and now we have type setting

科学里也存在——嗯，呃，对，就会有大量重复的、浪费掉的努力。嗯，我是说有时候重复这些经历是好事，但我们做得太多了。嗯，所以我觉得有一些办法，能让我们作为一个整体高效得多，嗯，也能通过改变我们的工作流程、让它们更现代一些，让数学对其他科学真正更有用。现在有那么多工具，嗯，不光是AI，甚至在 AI 之前的软件等等，做数学的过程一定会受到这些影响，对吧？我是说，它一定在某些方面变得更高效了。 >> 是的，有些事情确实更好了。嗯，你知道，我读研究生的时候，还很常见的做法是找秘书把你手写的论文打出来。你知道，所以你得写得非常仔细，然后交给

时代对照：陶读研时（1990年代初）论文还需秘书打字、人工改错。排版软件（如LaTeX）的普及是数学工作流为数不多的现代化环节。

replicate /ˈreplɪkeɪt/ *v.*
复现、重复（实验或结果）

34:50

Software which is which is very good and which is designed for mathematics. Actually the thing though is that it's often you have to invest some time in learning how to program a certain language or run some technical software. because the community mathematicians is very small and we don't have a lot of money. we're not a big market for the big software companies. the tools we have, they're often not the sort of the slick really user friendly things that you might get on your iPhone or something.

秘书打字，打完拿回来，有些错别字，你还得改，是个很痛苦的过程。是的。嗯，而且嗯，现在我们有了排版软件，非常好用，而且是专门为数学设计的。不过实际上问题在于，通常你得投入一些时间去学会怎么用某种语言编程，或者怎么运行某些技术软件。嗯，因为数学家这个群体很小，而且嗯，我们没有很多钱。嗯，对那些大软件公司来说，我们不是一个大市场。所以我们手上的工具，

数学界工具落后的经济学解释：共同体太小、经费少，不构成软件公司的市场，因此工具远不如消费级产品好用——这是「AI降低工具门槛」这一期望的背景。

slick /slɪk/ *adj.*
精致顺滑的、体验流畅的

35:22

And so there is sort of a barrier to entry to use these tools. so a lot of mathematicians they try to do things by pen and paper just because the friction of using these tools is so great. but one hope is that AI when used correctly, which is a big caveat, you know, can make these tools much easier to use. I think a lot of people think of computation as a as a sort of math basically and that math is the foundation of everything that we're doing in computing today. >> How do you explain the relationship between those two things which both go back thousands of years?

往往不是那种特别顺滑、特别好用的东西，不像你在 iPhone 上用到的那些。所以使用这些工具是有门槛的。嗯，所以很多数学家还是尽量用纸笔来做，就因为用这些工具的阻力实在太大了。嗯，但一个希望是，AI如果用对了——这是个很大的前提，你知道——是能让这些工具用起来容易得多的。我想很多人把计算看成基本上就是一种数学，嗯，而且认为数学是我们今天在计算领域所做的一切的基础。>> 这两样东西都能追溯到几千年前，嗯，你怎么解释它们之间的关系？

注意陶的措辞：「AI用对了（这是个很大的前提）可以让工具更易用」——他对AI的乐观始终附带可靠性前提，与后文「99%可靠仍会毁掉证明」相呼应。

barrier to entry *phr.*
准入门槛

friction /ˈfrɪkʃn/ *n.*
摩擦；（喻）使用中的阻力、不便

caveat /ˈkæviæt/ *n.*
警示、限制条件、但书

08 计算规模化与实验数学

35:59

>> So mathematicians have used computers forever really. I mean you know the abacus is an early computational device 2,000 years old. computers used to be a profession a human profession. So before electronic computers, the ones we have today, we had first of all mechanical computers which were used in the world wars and then like little adding machines that you had to turn with gears and things. and then and then there were human computers, people who were just very good at computation. So we've always had the use of computers. what has changed in the last 50 years is scale that you they became so fast and so cheap that you can do massive computations at scale and this has opened up for example the ability to do experimental mathematics. So science all sciences have a both a theoretical side and an experimental side. and usually it's roughly 50/50 in most fields, but math until the last few decades was kind of 99% theoretical, 1% experimental because computation was

>> 数学家其实一直都在用计算机。我是说，你知道，算盘就是一种早期的计算装置，有 2000 年历史了。嗯，「computer（计算者）」以前还是一种职业，一种人类的职业。所以在我们今天这种电子计算机出现之前，首先有机械计算机，在两次世界大战中用过，嗯，还有那种小型的加法机，你得用齿轮什么的去摇。嗯，然后，然后还有人肉计算员，就是一些非常擅长计算的人。所以我们一直都在使用「计算」。嗯，过去 50 年里改变的是规模——它们变得如此之快、如此便宜，以至于你嗯可以做大规模的计算，而这打开了比如说做实验数学的可能性。所有科学都既有理论的一面，也有实验的一面。嗯，通常在大多数领域里大致是五五开，但数学直到最近几十年，还基本上是 99% 理论、1%实验，嗯，因为计算太繁琐、太昂贵，而且嗯，而且用纸笔做事情就是

computer原是人类职业「计算员」；算盘约有两千年历史，机械计算机曾用于两次世界大战。陶的论点：50年来改变的不是「用计算」本身，而是规模。

abacus /ˈæbəkəs/ *n.*
算盘

37:02

So tedious, expensive, and just it was just so much easier to do things by pen and paper and we became very good at doing things by pen and paper. But now in this era of big data and extremely fast computers and now AI powered calculations, we can now do computation that isn't just brute force. Let's just make a table of 10,000 numbers or whatever. But let's make a table of 10,000 problems and what techniques solve which problems. this is something which you needed humans in the past to painfully tick off one by one. Yes, I can solve this one. No, I can't solve this one. But now we can get an AI to run through these. We can do new types of mathematical experiments that were just not feasible before at the scale that we needed. I've run a project recently where we basically posed 22 million algebra problems and [snorts] we got various AIs, not the fanciest AIs actually, but more sort of what we call good old fashioned AIs to solve almost all of them. And then

容易太多了，我们也变得非常擅长用纸笔做事。但是嗯，现在在这个大数据和超快计算机的时代，呃，还有现在由 AI 驱动的计算，我们能做的计算不再只是蛮力那种——「我们来列一张 10,000 个数的表」之类的。而是，我们来列一张 10,000 个问题的表，然后嗯，看看哪些技巧能解决哪些问题。嗯，这种事在过去是需要人一个一个痛苦地打勾的。是的，我能解这个。不行，这个我解不了。但现在我们可以让 AI 把这些跑一遍。我们可以做以前根本不可行的新类型的数学实验，在我们需要的那种规模上。嗯，我最近做过一个项目，我们基本上提出了 2200 万个代数问题，[吸鼻子] 然后我们用了各种 AI，其实不是最花哨的那种，而更多是我们所说的「老派 AI」，嗯，去解决其中几乎所有的问题。然后剩下 100 个硬骨头，

关键数字：数学长期是99%理论、1%实验（其他学科约五五开），因为计算太贵太繁琐。大规模计算让实验数学成为可能：从列一万个数变成列一万个问题、测试哪些技巧能解哪些问题。

brute force *phr.*
蛮力（穷举式、不讲技巧的计算方式）

tick off *phr.*
逐项核对、打勾

37:59

There was a hard core of 100 left that the humans ended up finishing off. and that was a very nice collaborative project. yeah. So we've always used computation but the scale is so different now that we it's enabled new ways to do mathematics that were just not feasible before >> and so I guess what are the implications of that of like mathematics at scale. It's interesting that the example you just used which was an experiment was the purpose of it just to see if it could be done or was there something else? Okay.

最后由人类收尾。嗯，那是个非常好的协作项目。嗯，对。所以呃，我们一直都在用计算，但现在规模太不一样了，以至于它催生了以前根本不可行的做数学的新方式。 >> 那我想问，这意味着什么呢？我是说「大规模的数学」意味着什么。很有意思的是你刚举的这个例子，那个实验——它的目的只是想看看这事能不能做成，还是说另有别的目的？好的。

2200万代数问题指陶2024年发起的Equational Theories Project：验证约2200万个代数恒等式间的蕴含关系，主要靠自动定理证明器等「老派AI」完成，最后约100个硬骨头由人类收尾。

hard core *phr.*
最难啃的核心部分（此处指剩下的最难的100题）

finishing off *phr.*
完成收尾、解决掉

38:33

>> It was it was a pilot project. I mean there's there is some mathematical value to it but it was designed to make it as easy as possible to collaborate. It was a fairly elementary type of math problem but not so elementary that you could just plug it into a computer and solve it. you did need some human assistance. Yeah. So it was a pilot project but very instructive and I hope to replicate this these sort of things in the future. yeah so I it means that we will start having large big math in the way we have big science projects in which are again mostly experimental projects in other disciplines. I mean so I already you know I code a little bit but I'm not a professional coder. but already like using an AI to plot a simple function you know solve a simple equation I can just ask it in natural language and it's gotten to the point where it's actually fairly reliable. I can and I have to go back and forth and check that it's it's

>> 那是个试点项目。我是说，它确实有一定的数学价值，但它的设计初衷是尽可能让协作变得容易。它是一类相当初等的数学问题，但又没有初等到你可以直接把它丢进计算机就解出来。嗯，你确实需要一些人的协助。对。所以它是个试点项目，但嗯非常有启发性，我希望将来能把这类事情再做几次。嗯，对，所以这意味着我们将开始出现大规模的数学，嗯，就像我们在其他学科里有大科学项目一样，嗯，那些同样大多是实验性的项目。我是说，我其实已经，你知道，我自己也写一点代码，但我不是专业的程序员。嗯，不过现在已经能做到，比如嗯，用 AI 画一个简单的函数图，你知道，嗯，或者解一个简单的方程，我可以直接用自然语言问它，而且已经到了相当可靠的程度。我可以，而且我还是得来回折腾，检查它嗯，

试点项目的设计逻辑：数学价值其次，验证「大规模协作是否可行」才是目的——选题刻意「初等但不能纯机器解决」，保证人与机器都有角色。

pilot project *phr.*
试点项目

39:31

It's doing things correctly. But I can now do things that I would not have bothered doing in the past because it was too timeconuming. so it is beginning to yeah, it's like having a semicompetent assistant, personal assistant that can do lots of menial tasks for you. but it still sometimes makes mistakes and so it's you can't quite offload all your cognitive labor to this assistance yet, but we're learning how to, incorporate unreliable but powerful tools in our into our workflow. It's not my understanding is it's not in a place I mean it's great at coding.

做得对不对。但我现在能做一些以前根本懒得做的事情，因为那太费时间了。嗯，所以它开始，对，就像是有了一个半靠谱的助手、私人助理，能帮你做很多杂活。嗯，但它有时候还是会出错，所以你还不能把你全部的认知劳动都甩给这个助手。不过呃，呃，我们正在学习怎么呃，把这种不可靠但强大的工具融入我们的工作流程。这不是——嗯，我的理解是它还没到那个程度。我是说，它写代码很强。

「半称职助手」是陶对当前AI的定位：能做大量杂活、让以前懒得做的事变得可行，但会出错，不能完全托付认知劳动——如何把「不可靠但强大的工具」融入工作流是核心课题。

menial /ˈmiːniəl/ *adj.*
琐碎低阶的、无需技能的（menial tasks 杂活）

offload /ˌɔːfˈloʊd/ *v.*
卸下、转嫁（负担、工作）

09 AI 时代的证明工作流

40:07

Absolutely. It's that's a that's an area that it seems to be incredibly proficient at. Yes. but it's not actually effective that effective at doing really advanced math. >> Not autonomously. >> right. >> Yeah. So, if there's a complex math task and there's an expert that can break it up into lots of little bite-sized pieces and it then you ask the AI to do one little piece and then you find some way to check the output and then you ask another piece. Okay, it's beginning to become useful there. So, it's you still have to pay attention but the net time taken to achieve a task can be reduced. So if a complex task would have taken 3 hours for you to do by hand, with a computer, you still need to go back and forth. You can't just press a button and make it and solve it.

绝对是的。那是一个它似乎极其擅长的领域。是的。嗯，但它在真正高深的数学上其实并没有那么有效。>> 自主去做的话是不行。嗯 >> 对。>> 是的。所以呃，如果有一个复杂的数学任务，而且有个专家能把它拆成很多小块，然后你让AI 去做其中一小块，然后你再想办法检查输出，接着你再让它做下一块。好吧，那样它就开始变得有用了。所以嗯，你还是得盯着，嗯，但完成一项任务所花的净时间是可以减少的。所以如果一个复杂任务本来要你手工做 3 个小时，嗯，用计算机的话，你仍然得来回折腾。你没法一按按钮就把它解决掉。

proficient /prəˈfɪʃnt/ *adj.*
精通的、熟练的

bite-sized /ˈbaɪtsaɪzd/ *adj.*
一口大小的；（喻）易于处理的小块

40:51

But maybe it just takes one hour now. so there's an acceleration, but it isn't yet a sea change of you know, now we can just press a button, you know, have a coffee and come back and the problem is solved. I think we have to reorganize our workflows a little bit. So the traditional way to solve a math problem is to is to sort of do this long chain of logical steps from get from hypothesis to conclusion you know maybe 100 steps and if any one of them is wrong the whole the chain of logic falls apart. So and this was kind of our standard way of writing proofs and it kind of works if you're humans and you and you can keep the entire proof in your head. but if you try to use AI to do some of these steps then even if the AI is like 99% reliable but you know it screws up 1% you know the whole proof can fall apart. so but there could be other ways to run a project in such a way that failure rates are more acceptable. >> like instead of just focusing on one

但现在也许只要一小时了。嗯，所以是有加速的，但还谈不上是那种翻天覆地的变化，嗯，你知道，就是现在我们只要按个按钮，你知道，去喝杯咖啡，回来问题就解决了。嗯，我觉得我们得把工作流程稍微重新组织一下。传统的解数学题的方式是，做一长串的逻辑推演，从假设一路走到结论，你知道，也许 100 步，而其中任何一步错了，整条逻辑链就垮了。嗯，所以这一直是我们写证明的标准方式，而且呃，如果你是人类，而且你能把整个证明装在脑子里，这套办法基本是奏效的。嗯，但是嗯，如果你想用 AI 来做其中一些步骤，那么即使 AI 有 99% 的可靠性，但你知道，它有 1% 的时候会搞砸，你知道，整个证明就可能垮掉。嗯，所以，但也可能有别的方式来组织一个项目，让失败率变得更可以接受。嗯>> 比如说，嗯，与其只盯着一个问题去解它，你知道，不如同时搞一批 100 个

结构性矛盾：传统证明是百步逻辑链，一步错全盘崩，因此99%可靠的AI仍不可用。这解释了为何AI辅助数学需要重新设计工作流，而不是直接替换人。

sea change *phr.*
翻天覆地的变化、根本性转变

41:52

Problem and trying to solve it, you know, have a have a cohort of a 100 problems that you'd like solved and apply these AIs and the AI would try their best on each on each of these problems and maybe they only solve 20% of the problems. but that's 20 problems solved, you know, and the AI sort of clear away all they can and then there's some residual hardcore problems that you escalate to the humans. >> Do you ever see a time where AI could be helpful like a collaborator?

你想解决的问题，把这些 AI 用上去，AI 会在每一个、每一个这样的问题上尽力去做这些问题，可能它们只解决了其中 20%。嗯，但那也是解决了 20 个问题，你知道的，而且AI 差不多把它们能清理的都清理掉了，然后就剩下一些特别硬核的残余问题，你就把这些交给人类去处理。>> 你有没有设想过某一天 AI 能像一个合作者那样帮上忙?

容错式工作流方案：从单点攻坚改为100题批量处理，AI能解多少解多少（哪怕只有20%），残余硬核问题再升级给人类——把AI的不可靠性转化为统计问题。

cohort /ˈkoʊhɔːrt/ *n.*
一批、一组（同类对象或人群）

residual /rɪˈzɪdʒuəl/ *adj.*
残余的、剩下的

escalate /ˈeskəleɪt/ *v.*
上报、升级（问题交给更高层处理）

42:21

>> Yeah. No, it's already happening. >> Yeah. >> The mathematicians who are working on an open problem, they talk to an AI, the AI supplies some ideas. right now what happens is that over half the ideas they supply are rubbish or [laughter and gasps] either something that they already thought of or they know won't work or are just completely irrelevant. but there's this minority, you know, 20% of the time they will come up with a new observation that the expert either didn't think of or they did know about but it didn't come to their head right away. and they just need to see that idea. they say, "Okay, let's push that idea further."

>> 有啊。不，这已经在发生了。>> 是啊。>> 那些在攻克未解难题的数学家，他们会和 AI 交流，AI 会提供一些想法。嗯，目前的情况是，它给出的想法有一半以上是垃圾，[笑声和惊叹声]要么是他们已经想到过的，要么是他们知道行不通的，要么就是完全不相关的。嗯，但是有那么一小部分，大概 20% 的时候，它会提出一个新的观察，是那位专家要么没想到的，要么其实知道但一时没想起来的。嗯，他们只是需要看到那个想法。嗯，他们会说：“好，我们把这个想法再往前推一推。”

对AI当前水平的坦率量化：超过一半的建议是垃圾（已想过的、行不通的、不相关的），约20%的情况能提出专家没想到或一时没想起的观察——价值在于加速筛选，而非替代思考。

rubbish /ˈrʌbɪʃ/ *n.*
垃圾；无价值的东西（英式口语）

42:59

Okay. and then they need to go back and forth a conversation. Okay, so I don't like this part of your argument, but let's try to make this part u more precise and so you have to work with it because it's it produces so much rubbish >> still that if you don't if you're not already an expert in the subject, it will more likely lead you astray than get you closer to the goal. But there are isolated examples now where there have been experts who have seen their accelerated the process of cycling through the bad ideas before finding the combination of good ideas that actually moves you forward.

好，然后他们就得来回对话。比如说，你论证中的这一部分我不太认同，但我们试着把这一部分说得更精确一些，嗯，所以你得跟它一起干活，因为它产出的垃圾实在太多了 >> 以至于如果你本身不是这个领域的专家，它更可能把你带偏，而不是让你更接近目标。但现在已经有一些个别的例子，有些专家确实看到了它加速了筛掉坏想法的过程，从而更快找到那些真正能推动你前进的好想法的组合。

重要限定：正因AI产出大量垃圾，非专家使用它更可能被带偏而非接近目标——AI辅助数学目前只对已有判断力的专家净有益。

lead you astray *phr.*
把你引入歧途、带偏

43:34

So it is happening already. You can get a long way just by mining what other mathematicians have already done. But it's just you know it's 100,000 papers out there. it's already too vast for even a human expert to keep up with. So that will be very useful for a long time. and at some point maybe they will they will blow us away with something that was not in the literature and they did something creative. It's not the way the current AI models are not designed that way. yeah, they're trained from data and so they by their design they have to usually produce things that are similar or at least combinations of fragments of things they see in existing data sets. But yeah, I [snorts] mean this is why web search for example was such a transformative tool. It made the internet suddenly extremely useful.

所以这确实已经在发生了。光是去挖掘其他数学家已经做过的工作，你就能走得很远。只不过，你知道，外面有十万篇论文，这个量已经大到连人类专家都跟不上了。所以嗯，这一点在很长一段时间里都会非常有用。嗯，也许在某个时刻它们会用某种文献里根本没有的东西震撼我们，做出真正有创造性的事。这不是——目前的 AI 模型并不是那样设计的。嗯，是的，它们是从数据中训练出来的，所以它们按其设计，通常只能产出与已有数据集中所见事物相似的，或者至少是这些东西的片段组合。但话说回来，我[轻笑]是说，这正是为什么比如网页搜索会是如此变革性的工具。它一下子让互联网变得极其有用。

现有文献约十万篇论文，已超出任何人类专家的跟进能力——AI作为「文献挖掘器」的价值将长期存在。陶同时指出LLM按设计只能重组已有数据的片段，创造性突破并非其机制。

mining /ˈmaɪnɪŋ/ *v.*
挖掘（信息、数据）（mine）

blow us away *phr.*
令我们大为震撼、惊艳

transformative /trænsˈfɔːrmətɪv/ *adj.*
变革性的

10 认知稀缺：绿色革命的类比

44:29

>> you know it's not just enough to have just all the data dumped out there in a pile. You know having efficient ways to extract the most useful things. I mean even if it doesn't create any new information just organizing the information that's already out there is it's an it's a very important step in research. >> What about the other end of the scale? There's a whole set of concerns about how AI is actually going to you know reduce and or the way we use it will actually negatively impact human cognition.

>> 嗯，你知道，光把所有数据一股脑堆在那里是不够的。有高效的方式把最有用的东西提取出来，我是说，即便它没有创造任何新信息，仅仅是把已有的信息组织起来，这在研究中也是非常非常重要的一步。>> 那另一端的情况呢？有一大堆担忧，关于 AI 究竟会怎样，嗯，削弱——或者说我们使用它的方式会对人类认知产生负面影响。

容易被低估的观点：即使不创造新信息，仅仅高效组织已有信息就是研究的关键一步——网页搜索让互联网「突然变得极其有用」是先例。

45:01

>> Yes. you know and our ability they've done some studies where they just you know they watched somebody and studied them and analyzed the results of them using it even for a little while and found that the cognitive load is so reduced that it actually could be quite bad for human brain. So do you are you concerned about that and particularly in the field of math? yes no there are there are real harms and we have to very carefully distinguish responsible uses of AI with the much larger irresponsible use cases. So an analogy would be with nutrition. so in the 20th century we had the green revolution you know so food production skyrocketed food became cheap and plentiful especially in the west. and so you know famines were the thing of the past.

>> 是的。嗯，还有我们的能力，他们做过一些研究，就是观察某个人，研究他们，分析他们哪怕只用了一小会儿之后的结果，发现认知负荷降低得太多，以至于这对人脑可能相当有害。那你对此担忧吗？特别是在数学这个领域？呃，是的，确实存在真实的危害，嗯，我们必须非常小心地区分负责任的 AI 使用方式和范围大得多的不负责任的使用场景。可以类比营养。嗯，20 世纪我们经历了绿色革命，你知道的，粮食产量飙升，食物变得便宜又充足，尤其是在西方。嗯，于是饥荒成了过去时。

主持人引用的研究指使用AI会显著降低认知负荷、可能损害大脑（如2025年MIT关于ChatGPT写作的脑电研究）。陶承认危害真实，随后展开他著名的「营养类比」。

cognitive load *phr.*
认知负荷（心理学术语）

skyrocketed /ˈskaɪrɑːkɪtɪd/ *v.*
飙升、猛涨（skyrocket）

famines /ˈfæmɪnz/ *n.*
饥荒

45:50

But as a consequence many people started developing eating disorders obesity and all the things associated with that. And so for the first time people had to actually consciously watch their diet, do their exercise. now this is things that in previous centuries you would not have to do. You know if you were a peasant working in the farm, you didn't have to do go to the gym or anything because this has happened naturally. but because food became too plentiful >> you know this is this issue came.

嗯，但结果是，嗯，很多人开始出现饮食失调、肥胖以及与之相关的种种问题。于是人们第一次不得不有意识地控制饮食、坚持锻炼。嗯，这些事在过去的几个世纪里你是不需要做的。你知道，如果你是在农场干活的农民，你不需要去健身房什么的，因为这些自然而然就发生了。嗯，但因为食物变得太充裕了 >> 嗯，你知道，这个问题就来了。

绿色革命：20世纪中叶的农业技术革命（高产品种、化肥、灌溉），使粮食产量飙升、饥荒在多数地区成为历史——但随之出现肥胖与饮食失调，人类第一次需要「有意识地」节食和锻炼。

eating disorders *phr.*
饮食失调（症）

obesity /oʊˈbiːsəti/ *n.*
肥胖（症）

peasant /ˈpeznt/ *n.*
（传统农业社会的）农民

46:22

Now this doesn't mean that the green revolution is a bad thing. We don't want to go back to >> the era of food scarcity but it means that while you solve one problem you create new responsibilities. So analogously AI could create you know could solve the problem of cognitive scarcity. you know that cognitive tasks which might be difficult for non-experts to do may become extremely cheap and some you just ask an AI to do things for you. but as with nutrition the downside is that you have cognitive disorders now you know and you have to watch your mental diet and you do have to you have to maintain mental exercise >> which you didn't need to in the past because you would naturally problem solve your way through life. I mean even before AI you could you know there are already people you know who have maybe had too privileged and upbringing who cannot problems solve their way through certain real life situations. and AI will exacerbate that trend. I

这并不意味着绿色革命是件坏事。我们并不想回到 >> 食物匮乏的年代，但这意味着你解决一个问题的同时，也创造了新的责任。类比来看，嗯，AI 可能会，嗯，解决“认知稀缺”的问题。你知道，那些对非专家来说可能很难完成的认知任务，可能会变得极其廉价，你只要让 AI 帮你做就行。嗯，但和营养一样，副作用就是现在会出现认知失调，你得注意自己的“心智饮食”，你确实必须保持心智锻炼 >> 而这在过去是不需要的，因为你在生活中自然而然就得靠解决问题一路走过来。嗯，我是说，即便在 AI 出现之前，你知道，已经有一些人，可能成长环境太优渥了，以至于在某些现实情境里没法靠自己解决问题。嗯，而 AI 会加剧这种趋势。我想会有一些人，嗯，只有在 AI

类比的落点：AI解决「认知稀缺」后，人们将需要「心智饮食」和「心智锻炼」——解决一个问题会创造新的责任，而不是要回到匮乏时代。这是本期最具传播力的观点。

analogously /əˈnæləgəsli/ *adv.*
以类似的方式、类比地

scarcity /ˈskersəti/ *n.*
稀缺、匮乏

exacerbate /ɪgˈzæsərbeɪt/ *v.*
加剧、使恶化

47:21

Think there will be people who can only solve things if the AI can guide them. and yeah the moment the power goes out or something they could be in real trouble. But overall it is a good thing. you know so I think many of the skills say a mathematician does right now with solving like calculating various math problems we will not do as often because we will automate them but there will be some communities of people who still do them you know I like you know we don't need to lift heavy weights all the time but there are communities of people who lift weights either competitively as a sport or as a hobby >> and so you know there are people who solve Rubik's cubes for fun and do it as fast as possible even though actually robots can actually solve cubes even faster now faster than that 1.3 second I saw this >> there's some really impressive robots you need special it bottleneck it becomes the cube needs to be very welloiled and so forth but yeah it's

能引导他们的时候才解决得了问题。嗯，是的，一旦停电什么的，他们可能就真的麻烦了。但嗯，总体上这是件好事。嗯，你知道，我觉得，嗯，数学家现在做的很多技能，比如计算各种数学题，我们以后不会那么频繁地去做了，因为我们会把它们自动化，但仍然会有一些人群继续做这些事。你知道，我打个比方，我们不需要一直举重物，但确实有一群人在举铁，有的是当竞技体育，有的是当爱好 >> 嗯，所以你知道，也有人为了好玩去拧魔方，而且要拧得尽可能快，尽管现在机器人其实拧得更快，比那 1.3 秒还快，我看到过 >> 有些机器人真的相当厉害，你得用特制的，瓶颈变成了魔方本身，它得非常非常润滑之类的，但确实，看这些真的挺震撼的，你要是有慢动作摄像机就能

举重与竞速魔方的类比：机器早已超越人类（魔方机器人纪录已达零点几秒），但人类照样把它们当运动和爱好——技能不会消失，只会改变存在形式。

bottleneck /ˈbɑːtlnek/ *n.*
瓶颈、制约因素

welloiled /ˌwelˈɔɪld/ *adj.*
润滑良好的；运转顺畅的（规范拼写 well-oiled）

48:18

It's quite impressive actually to see these you have a slow motion camera you can yeah >> so I don't think we will lose I mean individually by default we may lose certain skills but collectively as a species I think we will keep all these skills I mean but they will become more like sports and hobbies. you know, so you know, you may be able to do math. You know, you may not need to be good at calculus or something. I mean, you could still do that as a hobby. Maybe there'll be competitive calculus competitions >> or whatever. but it's not something that it won't be a barrier to working on some scientific problem that involves some advanced mathematics. It sounds like we'll live in a world where, you know, it'll be easy to appear as cognitively exceptional in some area because everybody else has become so lazy, but it's your hobby, >> right?

看到，是的 >> 嗯，所以我我我不认为我们会失去——我是说，从个体来看，默认情况下我们可能会丢掉某些技能，但作为一个物种，我认为我们会把这些技能全都保留下来。只不过它们会更像运动和爱好。嗯，你知道，所以，嗯，你知道，你可能还是能做数学。你知道，你可能不需要很擅长微积分什么的。我是说，你仍然可以把它当爱好来做。也许会有微积分竞赛 >> 之类的。嗯，但这不会成为你去研究某个涉及高等数学的科学问题的障碍。听起来我们会生活在这样一个世界里：在某个领域显得认知能力超群会变得很容易，因为其他人都变得太懒了，而这恰好是你的爱好 >> 对吧?

个体与物种的区分：默认情况下个体会丢失某些技能，但人类整体会以爱好和竞技的形式保留它们；且AI会移除「不擅长微积分」这类参与科学研究的门槛。

49:07

>> Yeah. Which [laughter] has already happened. I mean, you I mean, you can go on the internet and you can see people who are have perfected some very niche skill, you know, juggling or whatever. and that's great. I mean I think having intellectual skills as has become a hobby rather than a necessary part of your of your labor is a positive thing. >> Are you at all worried like for your students right now that they're using tools that could make them less you know I guess less effective mathematicians or maybe compromise their future as a mathematician.

>> 是啊。这[笑声]其实已经发生了。我是说，你上网就能看到有些人把某个非常小众的技能练到了极致，比如杂耍之类的。嗯，这挺好的。我是说，我觉得智力技能变成一种爱好，而不是你劳动中不得不做的一部分，是件积极的事。>> 你会不会有点担心你现在的学生，他们在用一些可能让他们变得，我想是变得没那么强的数学家，或者说损害他们作为数学家的未来的工具?

niche /nɪtʃ/ *adj.*
小众的、细分的

juggling /ˈdʒʌglɪŋ/ *n.*
杂耍抛球

49:40

>> It's become important to have conversations with the students saying that you know you can use these tools. there are good ways to use them and bad ways. so some instructors are saying yes you can use these tools but you must disclose that you're using them and show me the prompts. don't just show me the answers and because actually the prompts are also instructive. that I mean what we want to see is your thinking process and how were you stuck? and sometimes u the instructors who say here's a problem here is chat GPT's answer to it. It's incorrect. critique it. What is the problem?

>> 现在跟学生谈这些变得很重要，嗯，要告诉他们，你知道，你可以用这些工具，但用法有好有坏。嗯，所以有些老师会说：可以，你可以用这些工具，但你必须声明你用了，并且把提示词给我看。嗯，别只给我看答案，因为实际上，嗯，这些提示词本身也很有启发性。嗯，我们想看到的是你的思考过程，以及你在哪里卡住了。嗯，还有，有时候老师会说：这里有道题，这是 ChatGPT 给出的答案，它是错的。请批判它。问题出在哪儿?

教学层面的具体应对：允许用AI但必须公开提示词（prompts）——提示词本身暴露思考过程和卡壳位置；还可让学生批判ChatGPT的错误答案，训练判别力。

critique /krɪˈtiːk/ *v.*
批判性评析、评论

50:17

>> Of course, some people would then use another AI tool to critique it, but I think we do need to acknowledge that these tools exist and in the short term we can do some measures to like you know so inerson examinations are making a comeback. So during co we moved a lot of examinations work. but >> because of AI we are unfortunately reinstating some somewhat obsolete testing practices like having midterms in the classroom >> as that's a short-term measure I think before we figure out better ways to examine our students that acknowledge that AI is a powerful AI is a reality.

>> 当然，有些人接着就会用另一个 AI 工具去做这个批判，但是，嗯，我觉得我们确实需要承认这些工具的存在，短期内我们可以采取一些措施，比如，你知道，线下考试正在回归。疫情期间我们把很多考试搬到了线上。嗯，但 >> 因为 AI，我们不得不重新启用一些多少有点过时的测评做法，比如在教室里考期中 >> 这只是一个短期措施，我认为在我们想出更好的、承认 AI 是一种强大力量、是既成事实的考核方式之前，只能先这样。

因AI作弊风险，疫情期间转到线上的考试正被搬回教室。陶坦言这是「恢复某种过时测评方式」的短期权宜之计，长期需要承认AI现实的新考核设计。

reinstating /ˌriːɪnˈsteɪtɪŋ/ *v.*
恢复、重新启用（reinstate）

obsolete /ˌɑːbsəˈliːt/ *adj.*
过时的、被淘汰的

50:55

Yeah. So I mean the next generation is going to grow up using these tools and but we they need to distinguish the correct way to use them from the bad way. It's just like your food becomes plentiful. There's a there's a there's a good way to manage your diet and there's a bad way and you can't just ban food. Okay. That's the wrong approach. Okay. But you have to encourage good practices and discourage bad ones. >> Yeah. the sort of social technology that we need to properly adapt to AI doesn't certainly from a governance perspective doesn't feel like it's coming online fast enough. It's really it's trailing behind certainly how the you know sort of the tsunami of impact that technology is having in our lives. but universities are kind of at the front line of this and so do you feel like what I guess do you feel like they're getting it right as they navigate this space or >> well they are trying it would help if their funding situations and things if they had a more stable general

是的。我是说，下一代人会在使用这些工具中长大，但他们需要分清正确的用法和糟糕的用法。这就像食物变得充足一样，管理饮食有好的方式，也有糟糕的方式，而你不可能一禁了之。对吧，那是错误的做法。好，你必须鼓励好的做法，抑制坏的做法。>> 是的。我们要真正适应 AI 所需要的那种社会性技术，至少从治理角度看，感觉上线得不够快。它确实明显落后于科技对我们生活造成的那种海啸般的冲击。嗯，但大学在某种程度上处在这件事的最前线，所以你觉得——我想问的是，你觉得他们在应对这个局面时做得对吗？还是 >> 嗯，他们在努力。如果他们的经费状况之类的能好些，如果整体环境更稳定，那会更有帮助，所以这是 >>

「食物充足后不能靠禁食解决肥胖」的延伸：对AI一禁了之是错误做法，要鼓励好用法、抑制坏用法——治理等「社会性技术」落后于技术冲击是两人的共识。

tsunami /tsuːˈnɑːmi/ *n.*
海啸；（喻）铺天盖地的冲击

governance /ˈgʌvərnəns/ *n.*
治理、管治

trailing behind *phr.*
落在后面、跟不上

11 经费动荡与产学界线消融

51:51

Climate to do these so this is >> yeah so this is a moment where universities have to step up and reinvent education for the 21st century and yeah So people are trying to some very heroic efforts and experiments. yeah, unfortunately we're also fighting also other fires right now. >> Yeah, there's it's quite an onslaught of change and adaptation right now. >> the current administration is proving somewhat hostile, I guess, >> towards higher education. How's that impacted you and UCLA? So I mean the actual funding cuts themselves are bad enough but I think the worst thing is suddenly there's a loss a big loss of certainty at a time of great change where things were becoming uncertain anyway I mean there's lots of knock-on effects so the difference I mean we've had funding cuts in the past and you know budgets have fluctuate up and down but it there was a it was a stable process you know like maybe Congress would pass a bud a budget

是的，所以这是一个大学必须站出来、为 21 世纪重新发明教育的时刻，嗯，是的，嗯，所以人们在尝试，有一些非常英勇的努力和实验。呃，是的，不幸的是我们现在同时还在扑灭其他的火。>> 是啊，现在的变化和适应压力真的相当猛烈。>> 嗯，现任政府对高等教育表现得，我想说，有些敌意，>> 这对你和 UCLA 有什么影响？我是说，实际的经费削减本身已经够糟了，但我觉得最糟的是，确定性突然大幅丧失，而这正发生在一个巨变的时期，在本来就已经变得不确定的时候。嗯，我是说有很多连锁反应，所以，嗯，区别在于——我们过去也经历过经费削减，你知道，预算有涨有落，但那是一个稳定的过程，比如说国会可能通过一份预算，然后下一个财年，嗯，某个部门的某项预算

背景：2025年起特朗普政府大幅削减NIH、NSF等联邦科研经费并冻结多所大学拨款。陶强调实际削减之外，「确定性的突然丧失」才是最大伤害。

onslaught /ˈɑːnslɔːt/ *n.*
猛烈冲击、狂潮

hostile /ˈhɑːstl/ *adj.*
怀有敌意的

knock-on effects *phr.*
连锁反应、间接影响

fluctuate /ˈflʌktʃueɪt/ *v.*
波动、起伏

52:53

And then the next fiscal year you some budget for some kind of department would get raised by 5% or cut by 5% and but there was time to prepare it was not abrupt and what's different now is that there seems to be no regard for damage mitigation and you know you the administration makes a choice and they want to implement it by tomorrow that all this funding is cut and we have to scramble suddenly to preserve projects that need continuous support. We have to find ways to give out graduate students paychecks and things and we are doing all this firefighting you know emergency fundraising and so we are not doing as much you know experimental science or doing things like experimenting with new ways to use this incorporate AI or whatever because we have to do all these emergencies and then we can't budget now you know so normally if you have a three-year grant you can hire somebody for 3 years to be paid out the grant because you

上调 5% 或者下调 5%，但你有时间去准备，嗯，它不是那么突然。嗯，现在不同的是，嗯，似乎完全不考虑，嗯，损害的缓解。你知道，政府做了一个决定，就想明天就执行，说所有这些经费都砍了，我们就得突然手忙脚乱地去保住那些，嗯，需要持续支持的项目。我们得想办法给研究生发工资之类的，嗯，我们把精力都花在救火上，你知道，紧急筹款，所以我们没能去做那么多，你知道，实验性的科研，或者去尝试新的方式来，呃，嗯，把 AI 整合进来什么的，因为我们必须处理所有这些紧急情况，然后我们现在也没法做预算了，你知道，通常如果你有一笔三年期的资助，你可以雇一个人干三年，嗯，用这笔资助来付工资，因为，呃，

具体机制：过去预算涨跌有过程、可准备；现在政策要求次日生效，大学被迫救火式紧急筹款、保住需持续支持的项目，挤掉了实验性科研和AI工作流探索。

fiscal year *phr.*
财政年度

scramble /ˈskræmbl/ *v.*
仓促行动、手忙脚乱地应对

abrupt /əˈbrʌpt/ *adj.*
突然的、毫无过渡的

mitigation /ˌmɪtɪˈgeɪʃn/ *n.*
缓解、减轻（damage mitigation 损害控制）

firefighting /ˈfaɪərfaɪtɪŋ/ *n.*
救火；（喻）疲于应付紧急状况

53:54

Know you can you can have an expectation that you know barring some extremely unusual circumstances the funding will be dispersed. but we now we're now not able to do that. we can only budget for within our fiscal year. and so this stresses out our students because the we used to be able to guarantee yes I can I can support you for the next two years because I have funding for this. and now it's I might have funding. I will try my best, but it may be that you have you have no paycheck next year. and so that I think has been the most damaging out of all the I mean that's on top of actually getting the funding cut. so the funding is cut and then is restored.

你知道，你可以有一个预期：除非出现极其反常的情况，否则那笔经费是会如期拨付的。嗯，但我们现在做不到了。嗯，我们只能在本财年之内做预算。嗯，这让我们的学生压力很大，因为，嗯，我们以前能保证：是的，我可以支持你未来两年，因为我有这笔经费。嗯，而现在变成了：我也许有经费。我我我会尽最大努力，但也可能你明年就没有工资了。嗯，所以我觉得在所有这些当中，这是最具破坏性的。我是说，这还是在经费实际被砍之外的。嗯，所以经费被砍了，然后又恢复了。

最直接的人的代价：过去能向研究生承诺「未来两年经费有保障」，现在只能按财年预算、说「明年可能没工资」——不确定性直接打击最年轻的科研人员。

barring /ˈbɑːrɪŋ/ *prep.*
除非发生、若无（barring some circumstances）

54:39

The confidence has not been restored. and the morale has not been restored and so that has been very unfortunate. and it will take quite a bit of course correction to regain that level of predictability and trust. >> And for you are the is what's at stake in what's at stake in all of this? Is it more about the work that's happening right now that might be compromised or the long-term implications for the field if some of these people don't continue in it? Like what do you think? Yeah, >> the long term is the most serious air.

但信心并没有恢复。嗯，士气也没有恢复，所以这一点非常令人遗憾。嗯，而且要相当大力度的纠偏，才能重新赢回那种可预期性和信任。>> 那对你来说，这一切当中真正利害攸关的是什么？更多是关于那些正在发生的工作，还是现在这一点可能会受到损害，或者说，如果这些人不继续留在这个领域，会对整个领域产生什么长期影响？你怎么看？是啊，>> 长期才是最严重的问题。

「经费砍了又恢复，但信心没有恢复」：损害的核心是可预期性与信任，需要长期纠偏才能重建。陶认为长期影响远比短期缺钱严重。

morale /məˈræl/ *n.*
士气

course correction *phr.*
纠偏、路线修正

at stake *phr.*
利害攸关、成败在此一举

55:17

So shortterm we can do emergency things and shift some funds around and keep existing projects alive. and that's basically what we're doing now which but it comes at the expense of starting new things especially experimental things that are risky. so because of all these extra risk that has been imposed on us we don't take on any risks ourselves unless out of almost desperation you know like if the if the alternative is closing down then we will take some big risks.

所以短期内我们可以做一些应急处理，挪一挪资金，把现有的项目维持下去。嗯，这基本上就是我们现在在做的事，但代价就是没法启动新的项目，尤其是那些实验性的、有风险的项目。嗯，所以，正因为这些额外的风险被强加到我们身上，我们自己就不再去冒任何风险了，除非是走投无路了，你知道的，比如说，如果另一个选择就是关门的话下来，然后我们就会承担一些相当大的风险。

风险传导机制：外部强加的不确定性使机构自身风险偏好归零，只维持现有项目、不敢开新的实验方向——除非到了「不冒险就关门」的绝境。

at the expense of *phr.*
以牺牲…为代价

desperation /ˌdespəˈreɪʃn/ *n.*
走投无路、孤注一掷

55:50

>> We're also seeing huge number of mathematicians actually going into the tech companies and supporting their work. The priority there of course is going to be greater and greater computation not necessarily better and better math for the sake of theoretical math. What do you know are you concerned about that? What do you see as the implications of you know the tech sector basically attracting so much talent >> on the plus side? It's like I mean math is this is math moment to be actually be useful for many immediate issues. So, so AI in particular has this issue of unreliability, you know, that it can create these superficially convincing answers to questions, but often they're incorrect. but math is the one discipline which is somehow which has for centuries been refining how do you check whether something is really absolutely correct or not. And so mathematics in particular has sort of this honed the art of actually verifying various

>> 我们还看到，呃，大量数学家其实都进了科技公司，去支持他们的工作。那边的优先级当然会是越来越强的算力，而不一定是为了理论数学本身而追求越来越好的数学。你对这个……你知道，你会担心吗？你觉得科技行业基本上吸引走这么多，呃，人才会带来什么影响？>> 从好的一面看？就是说，我的意思是，数学——现在正是数学大放异彩的时刻，真正能够对很多眼下的问题都很有用。所以，AI 尤其存在一个不可靠的问题，就是说它可以给出表面上很有说服力的答案，但往往是错的。不过，数学是唯一一个学科，几个世纪以来一直在不断打磨：如何检验某个东西是否真的绝对正确。所以，数学在这方面可以说打磨出了一整套验证各种命题的技艺。所以这其实是一个非常好的组合，我认为

数学家流向AI公司的深层契合：AI的核心弱点是「表面可信但常错」，而数学是几百年来专门打磨「如何验证绝对正确」的学科——供需正好互补。

superficially /ˌsuːpərˈfɪʃəli/ *adv.*
表面上、肤浅地

honed /hoʊnd/ *v.*
磨炼、精进（hone the art of …）

56:47

Statements. And so actually it's a it's a very good combination and I think this is one of the reasons why many AI companies are actually very interested in hiring mathematicians and actually given that u academia is under their funding structures under attack it's actually it's also it's good to have a diverse set of career choices for junior colleagues and students I think the lines will blur in the future so with these I already collaborate with some tech companies and there are researchers there who work very productively with more traditional academics. with these collaborative projects we can have all kinds of people contribute including employees at big tech companies. I think yeah we have to reinvent. Yeah. So you know we have this ivory tower model where academics only work at academics. and I think yeah that has to change. we also being in ivory towers yeah there was this sort of old school sentiment that you know

这也是为什么很多 AI 公司其实非常有兴趣招聘数学家的原因之一。而且考虑到学术界在现有的经费结构下正受到冲击，所以对年轻同事和学生来说，有更多元的职业选择其实是件好事。我觉得未来这些界线会变得模糊，所以我已经在和一些科技公司合作，那里的研究人员和更偏传统的学者合作得非常非常高效。有了这些合作项目，各种各样的人都可以参与贡献包括大科技公司的员工。嗯，我觉得是的，我们必须重新构想这件事。是的。所以你知道，我们有这种象牙塔模式，学者只在学术界工作。嗯，我觉得这一点必须改变。嗯，我们也身处象牙塔中。是啊，以前有一种老派的观念，就是说，嗯，成功的学生会

> 陶对人才外流的态度出人意料地正面：学界经费受攻击之际，多元职业选择对年轻人是好事；他预计学界与业界的界线将模糊，自己已在与科技公司合作。

ivory tower *phr.*
象牙塔（脱离现实的学术环境）

57:47

You know, the successful students and stay in academia and the unsuccessful ones, they go out to, you know, be teachers or Wall Street or whatever. And that's a very old-fashioned attitude. I think yeah, it's good to have a diverse set of careers and people with different life experiences can contribute to these projects in different ways. So, I'm hoping to see lots of healthy collaborations. You know, there are some cultural differences as you say. you know, there's a lot more emphasis on short-term applications. sometimes there are some fights of academics want to release all the data that you made. Sometimes the companies want to keep some of them proprietary. so there are some teething issues with getting the collaboration right. but there's definitely a lot of scope for positive collaboration I think. Yeah, it's good to have actually particularly in this moment of funding uncertainty to have I guess industry collaborators that are

留在学术界，而不成功的那些就出去当老师，或者去华尔街之类的。这是一种非常过时的，嗯，态度。我认为，嗯，是的，职业道路多元化是好事，拥有不同人生阅历的人能以不同的方式为这些项目做出贡献。所以我很期待看到很多良性的合作。你知道，正如你所说，确实存在一些文化差异。你知道，（业界）对短期应用的重视要多得多。嗯，有时候会有一些争执，学者希望公开发布他们做出的所有数据，而公司有时想把其中一部分保留为专有的。嗯，所以在把合作理顺这件事上，确实存在一些磨合期的问题。嗯，但我觉得，确实存在很大的，嗯，正面合作的空间。是的。尤其是在当前经费不确定的这个时刻，能有一些产业界的合作伙伴其实是好事，他们对这些也

「成功的留学术界、失败的去华尔街」被他明确称为过时观念。产学合作的现实摩擦点：学者要公开全部数据，公司想保留专有部分——所谓「磨合期问题」。

proprietary /prəˈpraɪəteri/ *adj.*
专有的、私有的（不对外公开的）

teething issues *phr.*
初期磨合问题（本义为婴儿长牙的不适）

58:42

Interested in sort of >> yeah in some ways have aligned interests at the very least. Do you think you'd find any because you know there are these although they do tend to be very private in particular the social media companies that have like big audiences do you think there's hope for some sort of a civic collaboration in partnership with one of those companies >> I mean they have research arms you know they've I remember one there was a very cool presentation by a computer scientist gave a talk about the collaboration with I think Facebook and Facebook gave him access to the graph of who friends who in the >> and what they're able to predict.

感兴趣，就是说——是啊，某种程度上，至少双方的利益是一致的。你觉得你会找到那种——因为你知道，有这些，虽然它们往往非常封闭，嗯，尤其是社交媒体公司，嗯，它们拥有巨大的用户群体——你觉得有希望和其中某家公司建立某种公民层面的合作与伙伴关系吗？>> 我是说，嗯，它们有研究部门。嗯，你知道，它们，嗯，我记得有一次，呃，有一个非常酷的报告，是一位计算机科学家，嗯，做的一个演讲，嗯，讲的是和，我想是和 Facebook 的合作，Facebook 给了他访问那个图的权限，就是谁和谁是好友的那个关系图，在那个，嗯——>> 以及他们能预测出什么。

civic /ˈsɪvɪk/ *adj.*
公民的、公共事务层面的

research arms *phr.*
研究部门（arm 指机构的分支）

59:26

So they were able to predict given someone in the graph and just knowing who they know and who their friends are, who their friends are on Facebook, they can predict who their partner is. because the partner is usually someone who has a fairly distinct friend group than the than the than the original person, but it's still but has a has a strong connection. and so like it had like a 50 60% success rate in predicting the part just from know just from the network and but then the most interesting thing was the there were a couple cases where they incorrectly predicted the partner based on the network but then they checked back six months later and sometimes the relationship status changed [laughter] and That's amazing. It's a little spooky, but Oh, that's crazy.

所以，他们能够做到：给定图中的某个人，只要知道他认识谁，嗯，知道他在 Facebook 上的朋友是谁、他朋友的朋友是谁，他们就能预测出谁是他的伴侣。嗯，因为伴侣通常是这样一个人：其朋友圈子与那个人本身的圈子相当不同，嗯，呃，与那个原本的人不同，但仍然，呃，但有着很强的连接。嗯，所以它大概有 50%、60% 的，嗯，成功率仅仅根据网络关系来预测伴侣的准确率，但最有意思的是有那么几个案例，他们根据网络关系预测错了伴侣，但六个月后他们再回去核实有时候那个人的感情状态真的变了 [笑声] 这太神奇了。是有点瘆人，但是 哦，这太疯狂了。

> 指Backstrom与Kleinberg 2013年的研究：仅凭Facebook好友网络结构即可约50–60%准确率识别伴侣；预测「失败」的情侣半年后更可能分手——网络结构蕴含超出直觉的信息。

> **spooky** /ˈspuːki/ *adj.*
> 瘆人的、令人发毛的

12 AI 重写「智能」的定义

60:14

>> Yeah. So, I mean, yeah, there they definitely there is some research involved. I mean, >> so the question is what are we wrong about today? What fundamental belief do you think we should maybe >> I think one thing that this whole area of AI is teaching us is what is our idea of what intelligence is not really accurate, you know. the history of AI has been here's a task that only humans can do like maybe it is read natural language or win at chess or solve a math problem [snorts] and one by one someone finds some AI algorithm that also does that but okay we can now recognize spaces we can we can now understand speech and but you look at how it's done and it doesn't feel like intelligence like it's oh it was some trick you just you just cobble together these neural networks and we ran some algorithm >> and we were looking for some elusive intelligent way of thinking and we don't see it in the tools that actually solve our goals. but maybe

>> 是啊。所以，我是说，嗯，这方面确实有一些研究。我是说，>> 嗯，那么问题是：我们今天在哪些事情上是错的？你觉得有什么根本性的信念可能应该 >> 我觉得有一点是，整个AI 领域正在教给我们的是：我们对智能的理解其实并不准确。嗯，AI 的历史一直是这样：有一项任务只有人类能做，比如理解自然语言、下棋赢棋、或者解一道数学题 [哼笑] 然后一个接一个地，有人找出某种 AI 算法也能做到，但好吧，我们现在能识别图像了，我们现在能理解语音了，可是你去看它是怎么实现的，那感觉不像是智能。嗯，就好像，哦，这只是个小把戏，你只是把这些神经网络拼凑到一起，然后跑了个算法 >> 我们一直在寻找某种难以捉摸的、有智慧的思考方式，但我们在那些真正解决了我们目标的工具里并没有看到它。嗯，但也许这其实是因为智能并不是我们以为的那个样子。嗯，比如

「AI效应」现象：每当机器攻克一项「只有人类能做」的任务（下棋、识图、语音），人们就改口说「那只是技巧、不算智能」。陶将其反转：也许是我们对智能的定义本来就不准。

elusive /ɪˈluːsɪv/ *adj.*
难以捉摸的、难以企及的

cobble together *phr.*
草草拼凑而成

61:16

It's actually because intelligence is not what we think it is. so like large language models in particular have become very successful and a lot of what they're doing is just predicting the next token picking the next word in a sentence. and that doesn't sound like something which is intelligent like you know if you ask someone to improvise a speech and they don't have no preparation and at every moment they're just saying the next word that comes to their mind. It's human conscious dump. you don't think that this is this could actually work. but it does for LLM and maybe that's actually a lot of what humans do as well. you know, this response I'm giving you right now is not rehearsed. I have I didn't think about it that deeply, but it's you can get very far just by being in the moment and reacting. it's certainly there not you can't there's some things that actually do require careful deep thought, but you can do a lot of what seemingly seem like intelligent

大语言模型就特别成功，而它们做的很多事情不过是预测下一个 token，挑出句子里的下一个词。嗯，这听起来并不像是什么有智能的东西，比如说你要是让一个人即兴演讲，他们完全没有准备，每时每刻都只是说出脑子里冒出来的下一个词。这就是人类的意识流倾倒。嗯，你不会觉得这真的能行得通。嗯，但对大语言模型来说这就是行得通的，而也许人类做的很多事情其实也是这样。嗯，你看，我现在给你的这个回答就没有排练过。我并没有很深入地想过，但是，嗯，你光靠活在当下、随机应变，就能走得很远。嗯，当然，有些事情确实需要仔细的深度思考，但你可以几乎凭本能就完成很多看上去像是智能的任务，嗯，或者说靠自动驾驶模式。嗯，我觉得这是

核心反思：LLM只是逐词预测，听起来不像智能；但人类即兴说话同样是「说出脑中冒出的下一个词」——陶以自己此刻未经排练的回答为例，说明「活在当下地反应」能走很远。

improvise /ˈɪmprəvaɪz/ *v.*
即兴发挥、即席创作

rehearsed /rɪˈhɜːrst/ *adj.*
排练过的、事先准备好的

62:12

Tasks almost by instinct or by autopilot. and that's I think one thing that the age of AI is teaching us that maybe we're not quite as smart as we think we are sometimes. So do you think it's that we're what we thought was intelligence or what we mistook from intelligence was wrong or that maybe the thing that it is doing >> is intelligence and we're actually surprised by that our own intelligence is maybe that formulaic and that simple. >> Yeah. and I think it maybe we just embrace it, you know, that it's sometimes we think we're clever and we actually just did things, you know, came over genius idea, but it was actually just something that you remembered from some half from some buried conversation, you know, several years ago. That's still intelligence. and it's hard for us to sort of step back and see what intelligence is as an outsider because it is too tied emotionally to our sense of identity, right? But now that

AI 时代教给我们的一件事：也许我们并没有自己有时以为的那么聪明。那么你觉得，是我们以为的智能、或者说我们误认为是智能的东西错了，还是说也许它正在做的这件事 >> 就是智能，而真正让我们吃惊的是，我们自己的智能其实也就是这么套路化、这么简单。>> 是啊。嗯，我觉得也许我们就接受这一点吧，你知道，就是，嗯，有时候我们自以为很聪明，其实我们只是做了些事情，觉得自己冒出了个天才的点子，但那其实只是你从几年前某次埋在记忆深处的对话里记住的东西。那也仍然是智能。嗯，我们很难跳出来、以一个局外人的视角去看清智能到底是什么，因为它和我们的身份认同在情感上绑得太紧了，对吧？但现在我们有了另一个智能的模型，可以更

结论性观点：许多看似智能的行为出于本能或「自动驾驶」；自以为的天才想法可能只是多年前某次对话的深埋记忆——「那也仍然是智能」。人因身份认同难以客观审视智能。

formulaic /ˌfɔːrmjəˈleɪɪk/ *adj.*
公式化的、套路化的

autopilot /ˈɔːtoʊpaɪlət/ *n.*
自动驾驶；on autopilot 下意识地、机械地

63:16

We have this other model of intelligence that we can study a little bit more objectively I think we are learning a bit more about ourselves at the same time >> and so maybe we'll have a very different concept of what intelligence is. >> Yeah. and you know it can be sort of moment temporarily just disorienting but I think ultimately better. >> So it's the concept not just the concept of intelligence that changes but our definition of who we are changes too. >> Yeah. But that's not necessarily a bad thing. Mhm. [snorts] >> All right. Well, thank you. Thank you so much, Terrence. This is wonderful.

客观一点地去研究它，嗯，我觉得我们同时也在多了解一些自己 >> 所以也许我们对智能的概念会变得非常不一样。>> 是啊。嗯，你知道，这在一段时间里可能会让人有点迷失方向，但我觉得最终是件好事。>> 所以改变的不只是智能这个概念，我们对自己是谁的定义也随之改变了。>> 是的。但这不一定是坏事。嗯哼。[哼笑] >> 好的。那么，谢谢你。非常感谢，Terrence。这次聊得太棒了。

收束升华：AI提供了一个可被客观研究的「他者智能」，人类因此得以重新认识自己。智能概念的改写会暂时令人迷失，但陶认为最终是好事——连「我们是谁」的定义也随之改变。

disorienting /dɪsˈɔːrientɪŋ/ *adj.* 令人迷失方向的、让人无所适从的

63:48 旁白（片尾制作名单）

>> All right. >> Futurology is a Studio B and Waveland production with distribution from [music] Realm. Our executive producers are Nicholas Burguan, Nathan Gardell's, Don Nakagawa, Niels Gilman, [music] and Jason Hoke. Futurology is produced by Grant Slater, Alex Gardell's, [music] and Natalia Ramos. Our associate producer is Alyssa Martiny. Futurologyy's [music] theme music was composed by Marcus Begala. The show is mixed and mastered by Aaron Bastinelli. Special thanks to Heather Mason, [music] Olivia Derenzo, Carly Muleori, and Nick Godard. [music]

>> 好的。>> 《Futurology》由 Studio B 与 Waveland 制作，由 [音乐] Realm 发行。我们的执行制作人是 Nicholas Burguan、Nathan Gardell's、Don Nakagawa、Niels Gilman、[音乐] 和 Jason Hoke。《Futurology》由Grant Slater、Alex Gardell's [音乐] 和 Natalia Ramos 制作。我们的副制作人是 Alyssa Martiny。《Futurology》的 [音乐] 主题音乐由 Marcus Begala 创作。本节目由 Aaron Bastinelli 混音和母带处理。特别感谢Heather Mason、[音乐] Olivia Derenzo、Carly Muleori 和 Nick Godard。[音乐]

第二部分 核心句型 · 值得模仿的表达

1. as long as I can remember, I've always ...

“Yeah, as long as I can remember, I've always liked math adjacent things.”

「从记事起就一直...」：时间状语从句搭配现在完成时，谈论长期爱好、习惯或性格特点的地道开头，比 since I was young 更生动。

2. it's not about ... but (about) ...

“It's not about people individually creating genius ideas out of nothing but you know understanding what other people did”

否定加转折的对比结构，用于纠正常见误解、重新定义事物本质。议论中先破后立的观点句常用此框架。

3. If you're ..., you're in trouble. But if you're ..., you just ...

“If you're a mathematician and you ask to solve this equation and your solution doesn't work, you just start over”

平行假设句制造对比（工程师失败有代价，数学家失败可重来），排比加反转是口语论证中突出差异的利器。

4. either ... or ..., but in either case ...

“Either the primes have a lot of structure or they're very random. But in either case, we could prove that...”

二分穷举论证：先列出两种对立可能，再说明无论哪种都导向同一结论。写严密说理或风险分析时可直接套用。

5. What has changed ... is ...

“What has changed in the last 50 years is scale”

wh– 分裂句把信息焦点后置，强调「真正变化的是什么」。比 Scale has changed 更有力，适合总结性判断。

6. ... to the extent where ...

“It somehow increases your math ability in weird ways to the extent where so this phenomenon called rubber ducking”

表示程度之深以致出现某种结果，相当于书面化的 so...that；后接 where/that 从句引出具体表现。

7. while you solve one problem, you create ...

“It means that while you solve one problem you create new responsibilities”

while 引导让步对比：解决旧问题的同时带来新问题。讨论技术双刃剑、政策副作用类话题的万能句式。

8. it comes at the expense of ...

“That's basically what we're doing now which but it comes at the expense of starting new things”

「以牺牲...为代价」：讨论权衡取舍的高频搭配，主语通常是某种做法或收益，后接被牺牲的对象。

9. the moment ..., ...

“The moment the power goes out or something they could be in real trouble”

the moment 引导时间从句等于 as soon as，表「一旦…就…」，比 if 从句更具画面感和紧迫感。

第三部分 生词总表 · 复习用

词汇	音标	词性	释义	出现
abacus	/ˈæbəkəs/	n.	算盘	35:59
abhored	/əbˈhɔːrd/	v.	憎恶、痛恨（规范拼写 abhorred）	19:33
abrupt	/əˈbrʌpt/	adj.	突然的、毫无过渡的	52:53
analogously	/əˈnæləgəsli/	adv.	以类似的方式、类比地	46:22
anonymize	/əˈnɑːnəmaɪz/	v.	使匿名化	19:33
anthropomorphize	/ˌænθrəpəˈmɔːrfaɪz/	v.	拟人化	21:36
apprentice	/əˈprentɪs/	n.	学徒	31:59
archetype	/ˈɑːrkitaɪp/	n.	原型、典型形象	13:10
arithmetic progression	—	phr.	等差数列	16:49
at stake	—	phr.	利害攸关、成败在此一举	54:39
at the expense of	—	phr.	以牺牲…为代价	55:17
autopilot	/ˈɔːtoʊpaɪlət/	n.	自动驾驶；on autopilot 下意识地、机械地	62:12
back door	—	phr.	（安全系统中的）后门、暗道	20:27
balance the books	—	phr.	结账、使账目平衡	10:22
barrier to entry	—	phr.	准入门槛	35:22
barring	/ˈbɑːrɪŋ/	prep.	除非发生、若无（barring some circumstances）	53:54
behind closed doors	—	phr.	关起门来、私下里	24:55
bite-sized	/ˈbaɪtsaɪzd/	adj.	一口大小的；（喻）易于处理的小块	40:07
bliss	/blɪs/	n.	极乐、至福	8:26
blow us away	—	phr.	令我们大为震撼、惊艳	43:34
boasted	/ˈboʊstɪd/	v.	夸耀、自诩	19:33
bottleneck	/ˈbɑːtlnek/	n.	瓶颈、制约因素	47:21
brute force	—	phr.	蛮力（穷举式、不讲技巧的计算方式）	37:02
byproduct	/ˈbaɪprɑːdʌkt/	n.	副产品、附带结果	25:55
caveat	/ˈkæviæt/	n.	警示、限制条件、但书	35:22
civic	/ˈsɪvɪk/	adj.	公民的、公共事务层面的	58:42

cobble together	—	phr.	草草拼凑而成	60:14
cognitive load	—	phr.	认知负荷（心理学术语）	45:01
cohort	/ˈkoʊhɔːrt/	n.	一批、一组（同类对象或人群）	41:52
conjecture	/kənˈdʒektʃər/	n.	猜想（未被证明的数学命题）	16:49
course correction	—	phr.	纠偏、路线修正	54:39
crack it	—	phr.	破解、攻克（难题）	23:21
critique	/krɪˈtiːk/	v.	批判性评析、评论	49:40
crowdsourced	/ˈkraʊdsɔːrst/	adj.	众包的（向大众公开征集贡献的）	4:22
cryptographic	/ˌkrɪptəˈgræfɪk/	adj.	密码学的、加密的	19:33
cumulative	/ˈkjuːmjəleɪtɪv/	adj.	累积的、渐增的	26:50
dead ends	—	phr.	死胡同、走不通的路	25:55
definitive	/dɪˈfɪnətɪv/	adj.	最终的、定论性的	12:13
desperation	/ˌdespəˈreɪʃn/	n.	走投无路、孤注一掷	55:17
dichotomy	/daɪˈkɑːtəmi/	n.	二分法、两分对立	17:43
dip our toe into	—	phr.	初步尝试、试水	13:10
discernable	/dɪˈsɜːrnəbl/	adj.	可辨别的、可察觉的（规范拼写 discernible）	16:20
disclosed	/dɪsˈkloʊzd/	v.	披露、公开（disclose）	33:00
disorienting	/dɪsˈɔːrientɪŋ/	adj.	令人迷失方向的、让人无所适从的	63:16
divisible	/dɪˈvɪzəbl/	adj.	可整除的	16:20
eating disorders	—	phr.	饮食失调（症）	45:50
elusive	/ɪˈluːsɪv/	adj.	难以捉摸的、难以企及的	60:14
escalate	/ˈeskəleɪt/	v.	上报、升级（问题交给更高层处理）	41:52
exacerbate	/ɪgˈzæsərbeɪt/	v.	加剧、使恶化	46:22
famines	/ˈfæmɪnz/	n.	饥荒	45:01
finishing off	—	phr.	完成收尾、解决掉	37:59
firefighting	/ˈfaɪərfaɪtɪŋ/	n.	救火；（喻）疲于应付紧急状况	52:53
fiscal year	—	phr.	财政年度	52:53
flashy	/ˈflæʃi/	adj.	炫目的、抓眼球的	31:01
fluctuate	/ˈflʌktʃueɪt/	v.	波动、起伏	51:51

forefront	/ˈfɔːrfrʌnt/	n.	最前沿（at the forefront of 处于…最前沿）	0:00
formulaic	/ˌfɔːrmjəˈleɪɪk/	adj.	公式化的、套路化的	62:12
friction	/ˈfrɪkʃn/	n.	摩擦；（喻）使用中的阻力、不便	35:22
futilely	/ˈfjuːtəlli/	adv.	徒劳地、白费力地	33:00
giftedness	/ˈgɪftɪdnəs/	n.	（智力）天赋、资优	2:34
governance	/ˈgʌvərnəns/	n.	治理、管治	50:55
guildsman	/ˈgɪldzmən/	n.	行会工匠、行会成员	31:59
hard core	—	phr.	最难啃的核心部分（此处指剩下的最难的100题）	37:59
honed	/hoʊnd/	v.	磨炼、精进（hone the art of …）	55:50
hostile	/ˈhɑːstl/	adj.	怀有敌意的	51:51
human intervention	—	phr.	人工介入、人为干预	1:04
imposter syndrome	—	phr.	冒充者综合征（觉得自己名不副实的心理）	25:55
improvisational	/ɪmˌprɑːvəˈzeɪʃənl/	adj.	即兴的、随机应变的	5:56
improvise	/ˈɪmprəvaɪz/	v.	即兴发挥、即席创作	61:16
in tune	—	phr.	合拍、默契一致	29:55
instructive	/ɪnˈstrʌktɪv/	adj.	有启发性的、有教益的	9:24
instrumental	/ˌɪnstrəˈmentl/	adj.	起关键作用的（be instrumental in）	19:33
ivory tower	—	phr.	象牙塔（脱离现实的学术环境）	56:47
jealously guarded	—	phr.	严密守护的、秘不外传的	12:13
juggling	/ˈdʒʌglɪŋ/	n.	杂耍抛球	49:07
jumbled	/ˈdʒʌmbld/	adj.	杂乱的、顺序打乱的	6:48
knock-on effects	—	phr.	连锁反应、间接影响	51:51
layman's terms	—	phr.	外行能懂的话（in layman's terms 用通俗的话说）	15:25
lead you astray	—	phr.	把你引入歧途、带偏	42:59
leapfrog	/ˈliːpfrɑːg/	v.	跨越式超越（本义为跳背游戏）	0:00
menial	/ˈmiːniəl/	adj.	琐碎低阶的、无需技能的（menial tasks 杂活）	39:31
mental arithmetic	—	phr.	心算、口算	8:26
mining	/ˈmaɪnɪŋ/	v.	挖掘（信息、数据）（mine）	43:34
mitigation	/ˌmɪtɪˈgeɪʃn/	n.	缓解、减轻（damage mitigation 损害控制）	52:53

morale	/məˈræl/	n.	士气	54:39
multifaceted	/ˌmʌltiˈfæsɪtɪd/	adj.	多方面的、多元的	15:25
niche	/nɪtʃ/	adj.	小众的、细分的	49:07
nudge	/nʌdʒ/	v.	轻推；使微微推进	27:41
obesity	/oʊˈbiːsəti/	n.	肥胖（症）	45:50
obsolete	/ˌɑːbsəˈliːt/	adj.	过时的、被淘汰的	50:17
offload	/ˌɔːfˈloʊd/	v.	卸下、转嫁（负担、工作）	39:31
on the fly	—	phr.	临时地、边做边想地	5:56
onslaught	/ˈɑːnslɔːt/	n.	猛烈冲击、狂潮	51:51
open-ended	/ˌoʊpən ˈendɪd/	adj.	开放式的、无固定答案的	7:50
pacifist	/ˈpæsɪfɪst/	n.	和平主义者	19:33
peasant	/ˈpeznt/	n.	（传统农业社会的）农民	45:50
pilot project	—	phr.	试点项目	38:33
proficient	/prəˈfɪʃnt/	adj.	精通的、熟练的	40:07
proprietary	/prəˈpraɪəteri/	adj.	专有的、私有的（不对外公开的）	57:47
redundancy	/rɪˈdʌndənsi/	n.	冗余、重复浪费	31:59
rehearsed	/rɪˈhɜːrst/	adj.	排练过的、事先准备好的	61:16
reinstating	/ˌriːɪnˈsteɪtɪŋ/	v.	恢复、重新启用（reinstate）	50:17
replicate	/ˈreplɪkeɪt/	v.	复现、重复（实验或结果）	33:52
research arms	—	phr.	研究部门（arm 指机构的分支）	58:42
residual	/rɪˈzɪdʒuəl/	adj.	残余的、剩下的	41:52
restless	/ˈrestləs/	adj.	坐立不安的、闲不住的	8:26
revelation	/ˌrevəˈleɪʃn/	n.	令人恍然大悟的发现；启示	10:22
rubber ducking	—	phr.	小黄鸭调试法（向物体讲解问题以理清思路）	29:04
rubbish	/ˈrʌbɪʃ/	n.	垃圾；无价值的东西（英式口语）	42:21
scale	/skeɪl/	v.	可规模化推广（it didn't scale 无法复制推广）	5:56
scarcity	/ˈskersəti/	n.	稀缺、匮乏	46:22
scooped	/skuːpt/	v.	被抢先发表（be scooped 成果被人捷足先登）	12:13
scramble	/ˈskræmbl/	v.	仓促行动、手忙脚乱地应对	52:53

screw up	—	phr.	搞砸、弄糟	24:10
sea change	—	phr.	翻天覆地的变化、根本性转变	40:51
shoving	/ˈʃʌvɪŋ/	v.	用力推、猛推（shove）	27:41
showman	/ˈʃoʊmən/	n.	有表演欲/善于制造效果的人	31:01
skyrocketed	/ˈskaɪrɑːkɪtɪd/	v.	飙升、猛涨（skyrocket）	45:01
slick	/slɪk/	adj.	精致顺滑的、体验流畅的	34:50
spooky	/ˈspuːki/	adj.	瘆人的、令人发毛的	59:26
steeped in	—	phr.	沉浸于、深受…熏陶	14:08
subscribe to	—	phr.	赞同、信奉（观点、理念）	31:01
superficially	/ˌsuːpərˈfɪʃəli/	adv.	表面上、肤浅地	55:50
tedious	/ˈtiːdiəs/	adj.	冗长乏味的、繁琐的	1:04
teething issues	—	phr.	初期磨合问题（本义为婴儿长牙的不适）	57:47
thrives	/θraɪvz/	v.	茁壮成长；大放异彩（thrive）	0:00
tick off	—	phr.	逐项核对、打勾	37:02
tortured genius	—	phr.	备受折磨的天才（文化刻板形象）	13:10
toss out	—	phr.	（随口）抛出（想法）	27:41
toy models	—	phr.	玩具模型（高度简化、用于获得洞察的理论模型）	9:24
trailing behind	—	phr.	落在后面、跟不上	50:55
transformative	/trænsˈfɔːrmətɪv/	adj.	变革性的	43:34
tsunami	/tsuːˈnɑːmi/	n.	海啸；（喻）铺天盖地的冲击	50:55
unbounded	/ʌnˈbaʊndɪd/	adj.	无界的、无限的	16:49
verbalizing	/ˈvɜːrbəlaɪzɪŋ/	v.	用言语表达出来（verbalize）	29:04
vice versa	/ˌvaɪs ˈvɜːrsə/	adv.	反之亦然	11:18
wavelength	/ˈweɪvleŋθ/	n.	波长；on your wavelength 与你思路合拍	29:55
welloiled	/ˌwelˈɔɪld/	adj.	润滑良好的；运转顺畅的（规范拼写 well-oiled）	47:21
worldrenowned	/ˌwɜːrldrɪˈnaʊnd/	adj.	举世闻名的（规范拼写 world-renowned）	0:00

第四部分　理解自测 · 8 题

1. 陶哲轩最著名的成果是什么？内容是什么？
2. 他们证明该定理的核心策略是什么？
3. 哈代自夸数论「不可能有应用、不能作恶」，为何被历史反转？
4. 陶用什么类比来说明AI对人类认知的风险？结论是什么？
5. 陶如何评估当前AI在数学研究中的实际水平？
6. 关于经费削减，陶认为最大的伤害是什么？
7. 数学与工程、医学等学科相比，在教育上有什么独特价值？
8. AI的成功让陶对「智能」得出什么反思？

参考答案

1. 格林—陶定理（2004年与Ben Green合作证明）：素数中存在任意长度的等差数列（见第19–22段）。
2. 「结构与随机性二分法」：无论素数分布偏结构还是偏随机，两种情形都能推出等差数列存在，因此结论必然成立（第22段）。
3. 素数的性质如今是大多数密码算法的基础，互联网上的加密交易都靠素数运算打乱数据（第24段）。
4. 绿色革命的营养类比：食物充裕带来肥胖，人们才需要刻意节食锻炼；AI解决「认知稀缺」后，人也需要「心智饮食」和「心智锻炼」——解决一个问题会创造新的责任（第56–58段）。
5. AI给出的想法一半以上是垃圾，约20%的情况能提出有价值的观察；它擅长挖掘文献、批量清扫问题，但自主证明高深定理仍需专家把关，非专家反而容易被带偏（第52–54段）。
6. 不是削减本身，而是确定性与信任的丧失：无法跨财年预算、不能向研究生保证工资，机构风险偏好归零、不敢启动实验性项目（第65–69段）。
7. 数学中失败几乎零成本，是少数可以安全尝试「蠢办法」并从失败中学习的领域，而学生在其他领域被教育「不能失败」（第29段）。
8. LLM逐词预测看似不像智能，但人类即兴说话也是如此——也许人类智能比我们以为的更套路化；AI提供了一个可客观研究的参照，最终会改变我们对智能乃至对自我的定义（第75–78段）。