

# Variations of the Turing Test in the Age of Internet and Virtual Reality

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**Abstract.** Inspired by Hofstadter’s *Coffee-House Conversation* (1982) and by the science fiction short story *SAM* by Schattschneider (1988), we propose and discuss criteria for non-mechanical intelligence. Firstly, we emphasize the practical need for such tests in view of massively multiuser online role-playing games (MMORPGs) and virtual reality systems like *Second Life*. Secondly, we demonstrate *Second Life* as a useful framework for implementing (some iterations of) that test.

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## 1 The Turing Test: A Challenge

Artificial Intelligence is often conceived as aiming at simulating or mimicking human intelligence. A well-known criterion for the success of this endeavour goes back to Alan Turing: In [Turi50] he described an *Imitation Game* in which an interrogator gets into a dialogue with a contestant solely through a teletypewriter and has to find out whether the contestant is human or not<sup>a</sup>. Turing forecasts:

*I believe that in about fifty years' time it will be possible to programme computers, with a storage capacity of about  $10^9$ , to make them play the imitation game so well that an average interrogator will not have more than 70 per cent chance of making the right identification after five minutes of questioning.*

It is impressive how accurate the first part of this prediction has turned out valid (PCs with 1Gbit=128MBytes of main memory became common just around the end of the last millenium); whereas the Loebner Prize, announced for a computer to succeed with the second part of the prediction has not been achieved so far. The present-time world record holder **Elbot**<sup>b</sup> having convinced 3 out of 12 interrogators of being human. Nevertheless, it is considered only a matter of years until the first system passes the test.

### 1.1 Turing(-like) Test for Problem Resolution

The early successes in Artificial Intelligence led researchers in this field to be very optimistic. Nevertheless, it is important to realize the wildly discussed problems with AI. For instance, how and which 'human' rights and behavioral constraints should be applied to human-like 'robots'? Such deeply ethical questions underlie many famous science fiction stories and movies<sup>c</sup>; e.g. "*I, Robot*" by ISAAC ASIMOV with its *Three Laws of Robotics*, compare also the movie "*Bicentennial Man*" starring Robin Williams; or "*Do Androids Dream of Electric Sheep*" by PHILIP K. DICK, turned into the movie "*Blade Runner*" starring Harrison Ford. The plot of the latter specifically evolves around the serious problem of how to *detect* if the entity faced by an interrogator is mechanical (and may be 'killed', if so).

### 1.2 Turing Test and Internet

A major obstacle against passing the test is the vast amount of background information that every grown human has collected over the years of life; which

<sup>a</sup> It has been pointed out [Ster00] that the original paper's intention may have been subtly different; however, we adhere to what has become the standard interpretation of the Turing Test.

<sup>b</sup> <http://www.elbot.com/>

<sup>c</sup> In fact the authors are strongly convinced of Philosophy not just as a historical science but as a powerful method highly relevant to modern life as a guide and capable of shaping our future reality as anticipated in science fiction.

a computer program, typically running only for some hours, cannot. Instead, developers try to provide their candidate system with a data base of ‘knowledge/experience’ represented by pre-processed answers to specific topics and keywords.

The largest data base, in this sense, is of course the world-wide web. In particular we have in mind

- online encyclopedias, offering pre-compiled and objective background information on almost any conceivable topic;
- discussion boards, providing a more casual view and a subjective counterpart enabling a more human discussion.

Both can be efficiently accessed using popular search engines.

Of course, access to such external information may be considered cheating (and certainly is, if the program connects to an actual human say via ICQ, see Section 2.1). As a matter of fact the Loebner Prize rules quite reasonably:

*No entry will be tested by contest management which does not provide, on the transmittal media, all necessary programs, interpreters, etc.*

## 2 Problems with Mechanical Avatars in the Age of Internet

Section 1.1 recalled putative and philosophical problems arising with artificial agents in the future; in fact a not-too-near<sup>d</sup> future of material robots roaming our physical reality. In the present section we point out that the virtual reality of the internet has already turned the problem of (automatically) recognizing mechanical<sup>e</sup> avatars into a strongly present and practical one. We give four examples for this development.

### 2.1 Chatterbots, Spam, and Instant Messengers

In 1964–1966, JOSEPH WEIZENBAUM devised a computer program to parody “the responses of a non-directional psychotherapist in an initial psychiatric interview”. In spite of its technical simplicity (and to the surprise of its creator) this turned out to fool many ‘patients’. A series of successor software systems and improvements have followed, so-called **chatterbots**, enlargening the vocabulary and field of expertise like e.g. the *Artificial Linguistic Internet Computer Entity* A.L.I.C.E.<sup>f</sup>. In fact, this is the setting for the annual Loebner Prize in which the jury is presented a candidate system through a terminal with the explicit goal to determine whether it is human or not.

<sup>d</sup> *Blade Runner* for instance, produced in 1982, is set in the year 2019

<sup>e</sup> We avoid the term ‘*Artificial Intelligence*’ because of its philosophical ambiguities and in order to include the example in Section 2.3.

<sup>f</sup> <http://alicebot.blogspot.com/>

Infamous spam is probably known to anyone with a computer account: unsolicited electronic messages offering cheap<sup>g</sup> satisfaction to deep human desires (physical appearance, recognition, sex, money) as bait to the financial advantage of the original sender. The number of such emails literally flooding the internet raises the problem of automatically and reliably detecting and deleting (or at least marking) them as an assistance to the account owner who is otherwise in danger (or kept exceedingly busy) of missing the ‘true/important’ messages hidden between spam. Such tests, however, differ notably from Turing’s Imitation Game in which the underlying communication is immanently one-directional: The recipient of a putative spam email should not even try to reply in order to straighten out his/her suspicion, because that will most likely increase the black market ‘rating’ of his/her email address as ‘*active*’ and result in even more spam sent to it.

Nevertheless, instant messenger protocols, services, and clients like ICQ, Jabber, or AIM nicely complement email as a means of electronic communication: They are designed for immediate, low-overhead and informal exchange of relatively short messages and thus support a more interactive and sketchy (and volatile) form of communication, rather like remote dialogues than proper letters. The first author, for instance, can be reached at ICQ #232634449—or is that a chatterbot having replaced him? Indeed, many messenger clients provide plugins<sup>h</sup> for chatterbots to jump in, if the human user is unavailable. Some messenger accounts are even dedicated bots, for example ICQ #361718479 (primarily in German).

Presently, we are encountering a trend to synthesize (email-) spam and instant messaging to so-called *malicious chatterbots*: automated electronic advertisement, promotion, and luring with a new degree of interactivity that email is lacking and thus raising a very practical urge to detect and quell them in order to protect the user from such nuisance and danger. Like with email, such a detector should preferably work mechanically (i.e. no human interrogator), but unlike email, the aspect of interactivity in instant messaging prohibits any form of offline filter.

## 2.2 Game Bots

With the first computers (like the PDP), first computer games (like *Spacewar!*) followed soon. Since then, both computer technology and computer game design have evolved coherently. Presently the leads have even switched, video gaming graphics hardware being recognized as beneficial and used for scientific computing and number crunching with NVIDIA CUDA and ATI Firestream. Text-based computer role-playing games date back to the 1974 *Dungeons&Dragons* but were taken to an entire new level with the above advent of graphics capabilities. And finally throwing in the internet has resulted in the presently immense popularity of *Massively Multiplayer Online Role-Playing Games* (MMORPGs). These

<sup>g</sup> although true reward is well-known to require previous effort

<sup>h</sup> ALICE for instance can be merged with *Miranda*, see <http://addons.miranda-im.org/details.php?id=326>.

generally provide the user with a choice of goals and challenges of various degrees of difficulty. The more advanced ones require special items (virtual tools, weapons, skills, money) that can gradually be acquired and traded in-game; see e.g. Figure 1 in the appendix.

Now some players lack the patience or time of first passing through all the initial levels—and have their client mechanically repeat a more or less simple sequence of movements, each raising only a little amount of money<sup>i</sup> but over the course of virtual time (e.g. one real night) aggregates enough to cut short the intended game play and simply buy the desired item. Such a client extension is called a **Game Bot** and well-known for many MMORPGs such as *Diablo II*, *EverQuest*, *Lord of the Rings Online*, *Ultima Online* etc—and an obvious thorn in the side of the MMORPG’s operator who would very much like to (automatically) identify and, say, temporarily suspend such a user’s avatar.

### 2.3 Gold Farming

As an immediate measure against Game Bots as described above, modern MMORPGs have included a source of randomness into their game play. For instance, previously, some server-controlled ‘monster’ carrying a minor coin may re-appear reproducibly at a certain definite position after the user has killed it and temporarily left the place, so that the bot can simply repeat the previous sequence of moves in order to aggregate wealth; whereas now the monster would perhaps re-appear somewhere else, thus requiring more advanced and adaptive user interaction. However, MMORPGs’ (simplified) virtual economies<sup>j</sup> have spurred real-life counterparts: ‘Items’ (must not, but) can be purchased for actual money, e.g. on **eBay**. The wage differential and globalization have made this a lucrative form of business: computer kids, mostly in China and South Korea but also elsewhere, take over the role of the (insufficiently intelligent) Game Bots and perform (still mostly mechanical and repetitive) moves with their own avatar to gain virtual wealth and then sell it for real money on eBay to (mostly western) players.

This influence of the floating real world market to the (basically) fixed exchange rate system in the relatively small virtual world, has obviously a considerable impact on its economy.<sup>k</sup> Again, MMORPGs’ operators are therefore faced with the challenge of identifying and suspending certain accounts: this time not computer-controlled ones but those operated by ordinary humans who just happen to violate some in-game laws (formally and in the real world: end-user licence agreement or terms of service), typically from Asia and, being kids, often do not speak/write proper English. Such abuse has led regular *World of War-*

<sup>i</sup> The repetitive process of earning virtual wealth is called *grinding*, see [http://en.wikipedia.org/wiki/Grind\\_\(gaming\)](http://en.wikipedia.org/wiki/Grind_(gaming)).

<sup>j</sup> <http://ezinearticles.com/?id=1534647>

<sup>k</sup> With worldwide over 10 million subscribers in *World of Warcraft* converse effects are also noticable, see [http://news.cnet.com/2030-1069\\_3-5905390.html](http://news.cnet.com/2030-1069_3-5905390.html).

craft users to involve<sup>1</sup> ‘suspicious’ avatars into an online game chat: definitely a variant of the Turing Test!

## 2.4 Non-Player Characters in Second Life

MMORPGs traditionally feature a strict distinction between player characters (i.e. the real user’s virtual counterpart) and non-player characters (NPCs, e.g. the monstor mentioned in Section 2.3): the first must be controlled directly and interactively by a human, choosing from a *pre*-programmed selection of activities (move, fight, trade, chat, etc.); the latter are operated by the MMORPG server to exhibit a level of *fixed*-programmed artificial intelligence.

Such a distinction is largely removed in the online virtual reality system *Second Life*. Here, NPCs are entirely missing and so is, at least initially, any form of detailed scenery. Instead users may freely construct items and buildings by themselves. Further, they are encouraged to place and even to sell them on purchased virtual estate; see Figure 2. Moreover, in striking contrast to MMORPGs, these objects can be *user*-programmed to perform actions on their own. We demonstrate in Section 4.1 that the principal processing capabilities of such a user-created object in *Second Life* coincide with those of a Turing machine and may therefore be considered the strongest conceivable form of non-human intelligence.

When facing another avatar in *Second Life*, it is therefore not clear whether this constitutes indeed another user’s virtual representation or rather a literally ‘animated’ object; and we consider the problem of distinguishing the latter two cases as another variant of the Turing Test.

## 2.5 Summary and Classification

The original purpose of the Turing Test was setting a well-defined goal for the development of artificial intelligence. After 50 years a reconsideration is advisable. Specifically, the above examples suggest to reverse the focus: from devising a mechanical system to pass the test, towards devising test variants that reliably do distinguish (at least certain) mechanical systems from (other) human ones. Depending on the purpose and range of application, these variants of the Turing Test may

- i) employ either a human interrogator or an automated mechanical one.
- ii) distinguish either human from non-human contestants, or different classes<sup>1</sup> of human contestants; or even different classes of non-human ones.
- iii) proceed either passively/observant, or actively challenge the candidate.

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<sup>1</sup> This is, of course, highly controversial. It may be argued that in-game laws should be enforced by an in-game police and not by snitches. Also, the requirement of fluent English is dangerously close to racism. On the other hand the goal of the original Imitation Game was to distinguish a male from a female opposite, yet Turing is above any suspicion of sexism.

- iv) either be restricted to communication via teletype, or include more channels of perception provided by the virtual reality system under consideration such as observing the contestant’s movements in virtual space (Gold Farming), and perhaps even additional counterparts to human senses like hearing / sound of voice.
- v) either permit or prohibit the contestant’s online access to the internet.

### 3 Variations of the Turing Test

In Section 2 new challenges and applications which are not covered by the original Turing Test have been discussed. We report now on some known aspects as well as on some new deficiencies of this test. Then we discuss the Hofstadter-Turing Test as a stronger variant that mends some of them by taking into consideration more aspects of human intelligence. Finally, we prove the weaker Chomsky-Turing Test undecidable to a deterministic interrogator.

#### 3.1 Deficiencies of the Original Test

The Turing Test can be seen as having initiated, or at least spurred, Artificial Intelligence as a science. Nevertheless (or maybe rather: therefore) it is subject to various criticism and objections, some raised by Turing himself; cf. e.g. [OpDo08,SCA00].

**3.1.1 Restricted Interaction and the Total Turing Test:** Turing used teletypewriters, a technology of his time, as a means to hide to the interrogator the obviously non-human appearance of the computer hardware. He deliberately restricted communication and interaction in his test, so-to-speak *projecting* attention solely to the intellectual (if not platonic) features of the contestant. In science fiction movies on the other hand, physical appearance also plays an important role; recall Section 1.1. More precisely, Turing originally ignores most human senses entirely—channels of perception which in the 1950ies were indeed unforeseeable to artificial simulation.

However, this situation has changed dramatically with the rise of multimedia and virtual reality systems (recall Section 2.4) including not just 3D vision and directional sound but even haptic feedback [Robl06], yielding a rather drastic, undescribable experience of actual reality. In order to take this into account, the so-called *Total* Turing Test has been proposed as an advanced goal of Artificial Intelligence [Harn91].

**3.1.2 Physical Reality and Threat:** Extending the above reproaches, one may argue that mere interaction with the interrogator—even if sensual—does not suffice to classify as intelligent. A considerable part of human (as opposed to animal) existence arises from, and evolves around constructing new objects, tools, and weapons within and from its natural physical environment as a means

to meet with everyday challenges and threats. In fact, according to Darwin, such threats are the origin of and the catalyst to the degree of learning and creativity we consider typically human.

This is an aspect not covered even by the Total Turing Test—but well present in the Hofstadter-Turing Test described in Section 3.2 below.

**3.1.3 Anthropocentrism** is in our opinion the most serious deficiency, in fact of Artificial Intelligence as a whole: it starts with the (usually implicit) hypothesis that humans *are* intelligent (“cogito ergo sum”), and then proceeds in *defining* criteria for intelligence based on resemblance to various aspects of humans. Voluntarily equipping oneself with a blind spot seems like a strongest disproof against the initial hypothesis. On a less sarcastic level, anthropocentrism is known to have caused many dangerous and long-lasting errors throughout human history. Of course we have no simple solution to offer either [SCA00, p.509], other than to constantly remain open and alert against such fallacies.

### 3.2 Hofstadter-Turing Test

In 1988, DR. PETER SCHATTSCHEIDER published a science fiction short story “SAM” [Scha88] in the series of the computer magazine *c't*. It begins from the point of view of an unspecified ‘being’ finding itself wandering an increasingly complex environment, later revealed to be controlled by a ‘programmer’, and eventually arriving at a computer terminal where it starts setting up a similar virtual environment and wanderer, thus passing what is revealed (but not specified any further) as the *Hofstadter Test*:

*Im Hofstadter-Test wird das Programm mit einer Krisensituation konfrontiert, in der es ständig gezwungen ist, seine Lage zu überprüfen, um überleben zu können. Der Hofstadter-Test gipfelt in der Forderung, ein intelligentes, bewußtes Programm zu erstellen.*

This story may have been inspired by DOUGLAS R. HOFSTADTER’s *Coffee-House Conversation* [Hofs82] of three students, Chris (physics), Pat (biology), and Sandy (philosophy) ending with the following lines:

CHRIS: *If you could ask a computer just one question in the Turing Test, what would it be?*

SANDY: *Uhhh...*

PAT: *How about this: “If you could ask a computer just one question in the Turing Test, what would it be?”*

Observe the recursive self-reference underlying both, this last question and Schattschneider’s story “SAM” as well as Turing’s famous article [Turi36] proving by diagonalization and self-reference that the question of whether a Turing machine eventually terminates (i.e. the Halting problem, cf. e.g. Equation 1 on page 9) is undecidable to a Turing machine. Picking up [Scha88], we arrive at the following:



**Definition 1 (Hofstadter-Turing Test).** *For an entity to pass the Hofstadter-Turing Test means to devise*

- i) a virtual counterpart resembling its own environment and*
- ii) a computer program which succeeds in recognizing itself as an entity within this virtual environment and*
- iii) in turn passes the Hofstadter-Turing Test.*

**3.2.1 On the Self-Reference:** Because of Condition iii), Definition 1 is in danger of being circular. We want to address this important issue in three different ways.

*In classical logic* the problem can be removed by ‘unfolding’ the condition in requiring the existence of a countably infinite sequence of virtual environments and entities such that the  $(n+1)$ -st are created by and within the  $n$ -th. This does not provide any way of operationally performing this test but at least makes the definition valid.

*In practice and pragmatically,* once the first few<sup>m</sup> levels  $n$  have succeeded in creating their successor  $n+1$ , one would likely be content to abort any further recursion and state with sufficient conviction that the initial entity has passed the test.

*In his short story* SCHATTSCHEIDER gave another resort to the infinite re-iteration:

*Wenn der Spieler gewinnt, gibt es keine Wiederholungen. Bewußte Programme sind so verschieden wie du und ich. Sie können dem Kreislauf entrinnen. [...] Sein Ziel würde erreicht sein, wenn er ein Programm geschrieben hatte, das in der Lage war, sich selbst zu erkennen.*

We shall return to this remark in Section 5.

**3.2.2 Critical Account:** We readily admit that the Hofstadter-Turing Test does not provide the ultimate solution to the problems of Artificial Intelligence and mention three reproaches.

*Anthropocentrism* is, again, present in its strongest form by requiring our human physical world to be the first and thus modelled by all iterated virtual counterparts according to Condition i) environments.

In fact it seems that the common conception of a ‘virtual environment’ is highly biased and restricted. Even a critic of Platonic realism will find it hard to explain why a computer’s ‘digital world’ of 0s and 1s should *not* be considered an ontological reality but be required to reflect what humans consider (!) as real. Even more, questions of intelligence and consciousness are irrelevant within the abstract ‘world’ of programs; they only arise through the sociocultural interface of virtual role-playing systems.

<sup>m</sup> Section 4 shows that at least the first author has passed the initial 2.5 levels.

*The Problem of Other Minds*<sup>n</sup> is a well-known philosophical issue which arises here, too: Is the contestant (sequence!) required to exhibit and visualize the virtual environment he/she has created? Can we even comprehend it, in case it is a purely digital one? How about patients with locked-in syndrome: does the single direction of their communication capabilities disqualify them from being intelligent? In final consequence, one arrives at the well-known problems of Behaviorism.

“*Humans are intelligent*” used to be the first axiom of any test for true intelligence. But is actually any person able to pass (pragmatically at least some initial levels of) the Hofstadter-Turing Test? Recall he has to succeed<sup>m</sup> in creating a virtual entity of true intelligence.

### 3.3 Chomsky-Turing Test

As pointed out, several applications prefer an automated form of Turing-like tests (recall Item i) in Section 2.5). The present section reveals that this is, unfortunately, infeasible in a strong sense. Referring to the Theory of Computation we formally prove that even powerful oracle Turing machines (capable of solving e.g. the Halting problem) cannot distinguish a human contestant from the simplest (abstract model of a) computing device in Chomsky’s hierarchy, namely from a finite automaton.

**3.3.1 Reminder of the Theory of Computation:** In his PhD thesis [Turi39] Turing considered an extension of ‘his’ 1936 machine which he denoted as *o-machine*. This is nowadays known as **oracle Turing machine** and permitted during its computation to repeatedly submit a number (or binary string)  $x$  it may have calculated so far to some hypothetical external device called oracle and formalized as a set  $\mathcal{O} \subseteq \mathbb{N}$  (or  $\mathcal{O} \subseteq \{0, 1\}^*$ ). This device will then, and deterministically, provide within one step an either positive “ $x \in \mathcal{O}$ ” or negative answer “ $x \notin \mathcal{O}$ ” for the Turing machine to rely on in the subsequent steps of its calculation. Depending on the choice of oracle, such a machine can be very powerful; for instance for  $\mathcal{O} := H$  it can decide the (otherwise undecidable) Halting problem

$$H = \{\langle M \rangle : \text{Turing machine } M \text{ terminates on the empty input}\} \quad (1)$$

simply by passing the encoded input machine  $\langle M \rangle \in \mathbb{N}$ , whose termination is under question, right on to the oracle. On the other hand, even a machine with oracle access to  $H$  provably cannot decide the so-called relativized Halting problem  $H^H$ , that is the question of whether another given machine with oracle access to  $H$  terminates on the empty input or not. Iterating, one arrives at STEPHEN

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<sup>n</sup> The Problem of Other Minds raises following issue: Given that I can only observe the behaviour of others, how can I know that others have minds? And this issue particularly applies to the question of how to detect ‘mechanical minds’ [Tete94]. An answer to the latter seems at least as out of range as one to the former.

C. KLEENE’s infinite (in fact transfinite) hierarchy of oracle machines of strictly increasing computational power.

In the converse direction, namely concerning models of computation weaker than the Turing machine, NOAM CHOMSKY had devised a four-level hierarchy for classifying (originally natural, nowadays usually formal) languages. Among the big successes of Theoretical Computer Science (e.g. Turing Awards for MICHAEL RABIN and DANA SCOTT) was an equivalent characterization of each level, in terms of grammars generating the languages therein as well as in terms of machine models accepting these languages:

#	grammars	machines
0	unrestricted	Turing machines
1	context-sensitive	linearly space-bounded nondeterministic Turing machines
2	context-free	pushdown automata
3	regular	finite state machines

Finite state machines are generally considered as a model for simple control units like those of digital watches, elevators, or washing machines. In fact the Pumping Lemma reveals them as too weak to merely check a boiled down variant of syntactical correctness of a mathematical formula, namely the question of whether a given string  $x$  contains as many opening brackets (or 0s) as closing ones (or 1s).

Chomsky’s Hierarchy originally pertains to languages, that is to sets  $L \subseteq \{0,1\}^*$  of finite binary strings and their associated word problems of deciding, given some  $x \in \{0,1\}^*$ , whether  $x \in L$  holds or not; input  $x$ , output **yes/no**. However, the above machine models have natural and well-established extensions for dialogue-like problems. For instance, a Turing machine may ‘request’ further user input to be typed onto its tape by printing some special *prompt* symbol; and finite state machines become *transducers* such as *Moore machines* or, equivalently, *Mealy machines*.

**3.3.2 Strong Undecidability of the Chomsky-Turing Test:** As mentioned above, finite state machines and transducers (Chomsky level 3) are models of computation with immensely limited capabilities. Turing machines are located at the other end of the hierarchy (level 0). If we wish to include non-mechanical language processors, humans could be defined to reside at level -1. In which case the goal of (Artificial Intelligence and) the Turing Test amounts to (separating and) distinguishing level 0 from level -1.

The present section goes for a much more modest aim:

**Definition 2 (Chomsky-Turing Test).** *The goal of the Chomsky-Turing Test is to distinguish Chomsky level 3 from level -1.*

We establish that such a test cannot be performed mechanically. A first result in this direction is a well-known consequence of Rice’s Theorem in computability theory; cf. e.g. [Sips97, THEOREM 5.3].

**Fact 3.** *The language REGULARTM, defined as*

$\{\langle M \rangle : \text{the language } L(M) \subseteq \{0, 1\}^* \text{ accepted by Turing machine } M \text{ is regular}\}$   
*is undecidable to any Turing machine.*

It is, however, decidable by an appropriate oracle machine, namely taking REGULARTM itself as the oracle. Moreover, the above mathematical claim does not quite apply to the setting we are interested in: It supposes the encoding (Gödel index) of a contestant Turing machine  $M$  to be given and to decide whether  $M$  acts as simple as (but of course not is) a finite state machine; whereas in Turing-like tests, the contestant may be human and is accessible only via dialogue. Such a dialogue amounts to a sequence  $(x_1, y_1, x_2, y_2, \dots, x_n, y_n, \dots)$  of finite strings  $x_i$  entered by the interrogator and answered by the contestant in form of another finite string  $y_i$  upon which the interrogator adaptively enters  $x_{i+1}$ , the contestant replies  $y_{i+1}$ , and so on round by round. For this setting, we have the following replacement to Fact 3:

**Proposition 4.**

- i) It is impossible for any deterministic interrogator to recognize with certainty and within any finite number of communication rounds  $(x_1, y_1, x_2, y_2, \dots, x_n, y_n)$  that the answers  $x_i$  provided by the contestant arise from a transducer (Chomsky level = 3).*
- ii) It is equally impossible in the same sense to recognize with certainty that the answers arise from a device on any Chomsky level  $< 3$ .*

Thus, we have two separate (negative) claims, corresponding to (lack of) both recognizability and co-recognizability [Sips97, THEOREM 4.16]. More precisely, the first part only requires the interrogator to report “level = 3” within a finite number of communication rounds in case that the contestant is a transducer but permits the dialogue to go on forever, in case it is another device; similarly for the second part. Also, the condition of a deterministic interrogator is satisfied even by oracle Turing machines. Hence, this can be called a strong form of undecidability result.

*Proof (Proposition 4).* Both claims are proven indirectly by ‘tricking’ a putative interrogator  $I$ . For i) we first face  $I$  with some transducer  $T$ ; upon which arises by hypothesis a finite dialogue  $(x_1, y_1, \dots, x_n, y_n)$  ending in  $I$  declaring the contestant to be a transducer (“level = 3”). Now this transducer  $T$  can be simulated on any lower Chomsky level by an appropriate device  $D$  exhibiting an input/output behavior identical to  $T$ . Since  $I$  was supposed to behave deterministically, the very same dialogue  $(x_1, y_1, \dots, x_n, y_n)$  will arise when presenting to  $I$  the contestant  $D$ —and end in  $I$  erroneously declaring it to be a transducer. The proof of Claim ii) proceeds similarly: first present to  $I$  some device  $D$ ; which by hypothesis leads to a finite dialogue  $(x_1, y_1, \dots, x_n, y_n)$  and the report “level  $< 3$ ”. Now it is generally impossible to simulate  $D$  on a transducer since Chomsky’s Hierarchy is strict [Sips97]. However any fixed finite dialogue can be

hard-coded into some transducer  $T$ ; and repeating the interrogation with this  $T$  results by determinism of  $I$  in the same, but now wrong, answer “`level < 3`”.

□

Observe that the above proof of Proposition 4ii) involves transducers  $T$  of unbounded size in order to hard-code the fixed but arbitrary dialogue. In fact if an upper bound on the number of states of  $T$  is given, the problem does become decidable and turns into a well-studied topic within the field of *Model Checking*, cmp. e.g. [LeYa96, SECTION 7.1].

## 4 Implementing the Hofstadter Test in Second Life

Recall (Section 3.2, Definition 1) that the goal of the test is to implement a virtual reality system and an artificial entity therein which in turn passes the Hofstadter test. Fortunately, there is a variety of virtual reality systems available, so the first level of the test can be considered accomplished. However, in order to proceed to the next level, this system has to be freely programmable on the virtual level—and to the best of our knowledge, this is presently only supported by Second Life.

Section 4.1 demonstrates that the scripting language provided by Second Life indeed is Turing-complete, that is, a programming environment as powerful as possible. Further, we succeeded in implementing some few initial levels of the Hofstadter-Turing Test (Section 4.2) within Second Life .

### 4.1 Turing-Completeness of the Linden Scripting Language

Second Life is advertised, among others, for educational purposes. Correspondingly, DR. KENNETH SCHWELLER from the *Buena Vista University* (Iowa) has used it to implement and graphically visualize the operation of a Turing machine (see Figure 3). This seems to imply that Second Life is Turing-complete. However, closer investigation reveals some caveats and restrictions—which may not (yet) be of practical relevance but are important from the fundamental point of view of rigorous computability theory. In fact, the technical backbone of Second Life (running on a server farm of the **Linden Lab** company) raises doubts if it can actually provide the unlimited computational resources required for a truly Turing-complete environment. Specifically, the **Linden Scripting Language** (LSL) is primarily intended to animate objects in Second Life and each such script is limited to an overall memory consumption of at most 16kB. Although this may seem sufficient for most practical purposes arising in Second Life, a digital computer with constant-size storage cannot be Turing-complete because the question of its termination (as opposed to the Halting problem of a Turing machine) is decidable to a Turing machine; cf. e.g. [Sips97, p.178]. However, this seemingly fundamental restriction can be avoided using the trick of cascading: A script executed within an object may initiate an unlimited number of further scripts and send messages to them. In this way one can thus implement a linked list of unbounded length and linearly accessible via message passing forth and back: just like a Turing machine’s tape.

## 4.2 Two-And-Half Iterations of the Hofstadter-Turing Test

We have succeeded in implementing within Second Life the following virtual scenario: a keyboard, a projector, and a display screen. An avatar may use the keyboard to start and play a variant of game classic **Pac-Man**, i.e. control its movements via arrow keys; see Figure 4. (For implementation details, please refer to [Neu09, SECTION 4].) With some generosity, this may be considered as 2.5 levels of the Hofstadter-Turing Test:

- 1st:** The human user installs Second Life on his computer and sets up an avatar.
- 2nd:** The avatar implements the game of **Pac-Man** within Second Life.
- 3rd:** Ghosts run through the maze on the virtual screen.

Observe that the ghosts indeed contain some (although admittedly very limited) form of intelligence represented by a simple strategy to pursue pacman.

## 5 Concluding Remarks

We have suggested variations of the (standard interpretation of) the Turing Test for the challenges arising from new technologies such as internet and virtual reality systems. Specifically to the operators of MMORPGs and of Second Life, the problem of distinguishing mechanical from human-controlled avatars is of strong interest in order to detect putative abuse. Indeed, contemporary multimedia technology makes it much easier for an artificial being to convincingly resemble a human's virtual counterpart, thus obviating Turing's original restriction of purely teletypewriter-based interaction. Correspondingly (and in spite of the underlying anthropocentrism) it seems fair to require a virtual artificial intelligence to become aware of (and self-aware within) its virtual environment; and to employ it: this leads to the Hofstadter-Turing Test.

### 5.1 On Levels of Reality and Their Interaction

The question of ontology is an old philosophical one: what is real(ity)? This term, however, has been "hijacked" and restricted in computer science to information representation by means of data structures and for data exchange. In the context of virtual reality, though, one returns to the original meaning: are the digital worlds of World of Warcraft and Second Life 'real'? For many of their millions of human users/inhabitants, they at least constitute a strong surge to spend large parts of their life online, often on the verge of addiction. There, they meet friends, create homes, fight enemies, do commerce etc. and may choose and alter their appearance, thus being released from any physical impairments; exempted even from mortality and the laws of physics! It seems fair to say that such users *transit* at least partly to this new reality—which by itself is not necessarily bad at all; and which deserves the real world's verdict of addiction only because the transition remains incomplete.

An particular feature of the Hofstadter-Turing Test are the iterated levels of virtual reality it requires to be created one within another. Each one of these iterated levels can be seen as an encapsulated virtual reality, transparently contained by the one at the next higher level, like the skin layers of an onion. Similarly, behind the visible virtual reality of Second Life consisting of ‘idealized’ (i.e. platonic) geometric/architectural objects and avatars, there lies hidden the invisible and abstract virtual reality of programs and scripts that control and animate these objects.

This suggests an interesting (new?) approach to the philosophical problem of ontology: maybe reality should generally be considered composed of layers. In fact such a concept is present in many religions, although going in the opposite direction: where Hofstadter-Turing proceeds recursively to inner and inner layers, Buddhist cosmology for instance promotes a hierarchy of ‘realms’ ranging from *naraka* up to *Brahma*, from which all lower worlds can be perceived and as a means to break out from the infinite cycle of rebirth and to raise on this hierarchy, Buddha teaches (self-)cognition and enlightenment—which resembles Schattschneider’s proposed resort from the infinite recursion in the Hofstadter-Turing Test, recall Section 3.2.1.

Less esoterically speaking, the possibility and means to break through the confinements of one’s reality seems interesting enough. In terms of levels of realities, this includes the question of whether and how different such levels may interact. That a higher level can influence a lower one, should be pretty obvious from the above examples: the short story SAM, the Hofstadter-Turing Test, MMORPGs, and Second Life. But careful reconsideration reveals also effects in the converse direction:

- A video game addict socially isolating himself, loosing his job and/or health.
- Virtual items being sold for real money as in Gold Farming; cmp. Footnote<sup>k</sup>.

In fact the virtual success of a virtual reality system is closely tied to its owner’s economic situation in real life. So close that it has resulted in

- actual law-suits for breach of ‘virtual’ laws and unfair trade practices (see Bragg vs. Linden Lab).

## References

- [Harn91] HARNAD, STEVAN: “Other Bodies, Other Minds: A Machine Incarnation of an Old Philosophical Problem”. In *Minds and Machines* 1 pp.43–54 (1991).
- [Hofs82] HOFSTADTER, DOUGLAS R.: “The Turing Test: A Coffee-House Conversation”. In: Hofstadter, Douglas R. (Edt.); Dennett, D. (Edt.): *The Mind’s I: Fantasies and Reflections on Self and Soul*. Penguin Books London UK (1982) pp.69–95; compare <http://www.cse.unr.edu/~sushil/class/ai/papers/coffeehouse.html>
- [LeYa96] LEE, DAVID; YANNAKAKIS, MIHAILIS: “Principles and Methods of Testing Finite State Machines—A Survey”. In *Proceedings of the IEEE* 84:8 pp.1090–1123 (1996).

- [Mill73] MILLAR, P.H.: “On the Point of the Imitation Game”. In: *Mind* **82** (1973), pp.595–597.
- [Neu09] NEUMANN, FLORENTIN: “*Der Hofstadter-Turing-Test als anwendungsorientiertes philosophisches Problem am Beispiel von Second Life*”, Bachelor thesis, University of Paderborn (2009); available at <http://www.upb.de/cs/ag-madh/PapersPostscript/fneumann.2009.pdf>
- [OpDo08] OPPY, GRAHAM; DOWE, DAVID: “The Turing Test”. In *Stanford Encyclopedia of Philosophy* (May 2008); <http://plato.stanford.edu/entries/turing-test/>
- [Robl06] ROBLES-DE-LA-TORRE, GABRIEL: “The Importance of the Sense of Touch in Virtual and Real Environments”. In *IEEE Multimedia* **13** pp.24–30 (2006).
- [Scha88] SCHATTSCHNEIDER, PETER: “SAM”. In: *c't Magazin* **6** (1988) pp.214–220; available at <http://www.upb.de/cs/ag-madh/WWW/ziegler/Schattschneider88.pdf>
- [SCA00] SAYGIN, AYSE P.; CICEKLI, ILYAS; AKMAN, VAROL: “Turing Test: 50 Years Later”. In: *Minds and Machines* **10:4** (2000) pp.463–518.
- [Sips97] SIPSER, MICHAEL: “*Introduction to the Theory of Computation*”, PWS Publishing (1997).
- [Ster00] STERRETT, SUSAN G.: “Turing’s Two Tests for Intelligence”. In: *Minds and Machines* **10** (2000), pp.541–559.
- [Tete94] TETENS, HOLM: “*Geist, Gehirn, Maschine: Philosophische Versuche über ihren Zusammenhang*”, Reclam (1994).
- [Turi36] TURING, ALAN M.: “On Computable Numbers, with an Application to the Entscheidungsproblem”. In: *Proc. London Math. Soc.* **42:2** (1936) pp.230–265.
- [Turi39] TURING, ALAN M.: “Systems of Logic Based on Ordinals”. In *Proc. London Math. Soc.* **45** pp.161–228 (1939).
- [Turi50] TURING, ALAN M.: “Computing Machinery and Intelligence”. In: *Mind* **59** (1950) pp.433–460.



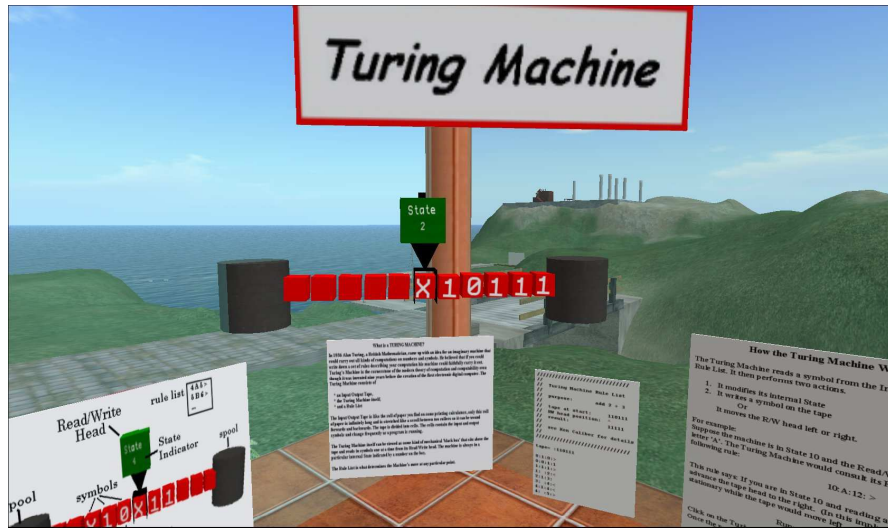
## A Screenshots



Fig. 1. Diablo II: 3 players are earning items after a fight, storing them in the players inventory.



Fig. 2. Second Life in user view



**Fig. 3.** A virtual Turing machine implemented by PROF. DR. KENNETH SCHWELLER and students from the *Buena Vista University, Iowa* in Second Life at coordinates <http://slurl.com/secondlife/Buena%20Vista/87/72/24>



**Fig. 4.** An avatar playing a variant of game classic Pac-Man within Second Life available at coordinates <http://slurl.com/secondlife/Leiplow/176/136/33>