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Preemptive Futures: Entropic and Negentropic Information in Speculative Design

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Preemption is an anticipatory action taken to secure first-options in maximising future gain and/or minimising loss. For instance, in risk management, responses are planned before a crisis takes place; such preemptive decisions are made based on speculations of possible future(s), directed by information feedback and analysis from a variety of sources. A systematic formulation of preemption and its relationship to computation are deeply rooted in the history of WWII; in the big data era, preemption is further augmented by the collaboration of human and machine intelligences, urging a rethink on how information is produced and used. By tracing a timeline of events around the conceptualisation of information, this paper aims at understanding the design and planning implications of preemptive decisions and how it may help us in rethinking speculative design. This paper first revises the idea of 'information' through a historical and theoretical study, and how it had been defined differently through the notion of entropy by Norbert Wiener, Claude Shannon, and Erwin Schrodinger from fields of cybernetics, information, and quantum theories. It discusses entropy from three perspectives: information compression and reconstruction, information entropy and energy entropy, interpolation and extrapolation. Finally, based on entropic and negentropic use of information, this paper rethinks the roles of speculation and preemption in today's design context, especially their applications in the collaborative intelligence of humans and machines within distributed, open source networks.

Keywords preemptive design, speculative design, entropy, negentropy, collaborative intelligence

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1. Introduction

Preemption has various meanings in different disciplinary contexts at different scales. For instance, futures markets, health insurance, and multitask operating systems (OS) are forms of micro-scale preemption that distribute risks and work to a larger community; military strikes, state preemption, and geoengineering are forms of macro-scale preemption that minimises options of the opponents in securing first-rights (Anderson, 2010). Although preemption can take different forms, it generally has speculative and anticipatory qualities, with present actions informed by a multiplicity of possible future(s) (Malik, 2016). The 'preemptive' frames design and planning as sets of iterative processes that feedback between decisions and their physical manifestations; sometimes maximising one's choices rather than generating definitive solutions; in most cases, it is meant to continue an infinite game for the overall survival of a system (Carse, 2013). For instance, HKSAR's (2021) quarantine provisions with Restriction-testing Declaration is a form of preemptive planning, iteratively adjusted based on weekly assessments to prevent wider contamination, which contributed to almost a year of near-zero COVID cases. It is inferred based on sensory data from a network of distributive devices (i.e. a government-developed app *LeaveHomeSafe* stores individual's visit records on local devices), crowdsourcing information on contamination flows between atomic units of the city with the larger transportation system (HKSAR, 2020). The preemptive decisions parameterised pandemic contingencies within a set of socioeconomic constraints developed along a time axis, and the sensory becomes an iterative feedback process that cannot be cognitively separated from our inference and actionistic systems. Together, these systems form one of the preemptives.

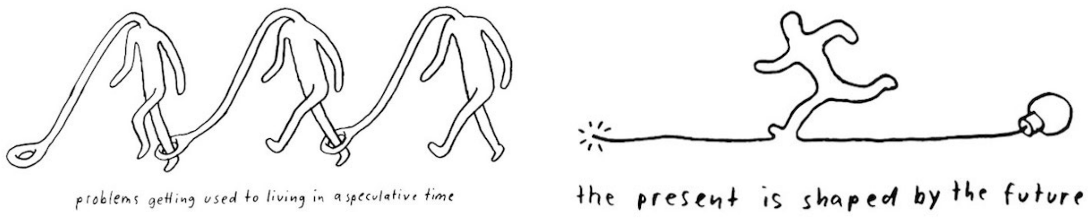


Fig. 1. Time complexity in preemptive actions, such as preemptive policing (Malik, 2016).

The etymology of 'preemption' can be traced back to c. 1600, from *pre*- 'before' and *emption* 'purchase' - '*a purchase by one before an opportunity is offered to others, originally as a right*', rooted in the colonial history of *preemptive land* and *preemptive war* (etymonline, n.d.). The former can be traced back to the US's *Distributive Preemption Acts* of 1830 and 1841, '*giving squatters a right of first refusal to purchase land they had occupied prior to its being opened for sale [...] Congressmen who favoured squatters' rights would also favour moving Indian tribes out of the old southwest*' (Carlson & Roberts, 2006). The latter originated from the *Caroline Affair* of 1837, where British Troops crossed Canadian borders to defeat rebels, and an African-American was shot to death; the British argument of preventive strike established the principles of ‘anticipatory self-defence’ within international law (Jones, 1976). In view of this history, it is important to keep in mind that preemption is often political - it is used to plan and justify actions based on future(s) that are yet to occur. But rather than suffocating ourselves with the geopolitical rectitudes that would necessitate preemption, this paper wishes to explore its conceptual democratisation in the everyday computational design context. The speculative nature of preemption puts on the design table the worst, best and most mundane kinds of scenarios and the probability distributions of each to maximise design profit.

Anderson (2010) wrote extensively on how anticipatory actions led to the planning of future geographies that are made and lived in the name of preempting threats to liberal-democratic life. Mazereeuw (2015) from the MIT Urban Risk Lab has been looking into participatory risk management - ‘*in a field that has traditionally been the domain of emergency managers and engineers, we bring preemptive design and community engagement into the risk-reduction equation*’. Bratton’s (2019) Terraforming program speculated on planetary-scale preemption as ‘*a viable plan, but also to the refusal of bad ones if necessary [...] speculative design must focus on what is so deeply functional as to be unlikely; and that, finally, the future becomes something to be prevented as much as achieved*’. IBM (n.d.) worked with preemptive consultants to deliver comprehensive compliance and end-to-end computational solutions, indexing and time-stamping messages for search efficiency, scalability and security across an international network of communication. Gill’s (2012) theory on *collaborative intelligence* characterised ‘*multi-agent, distributed systems where each agent, human or machine, is autonomously contributing to a problem-solving network*’. Within distributed, open source networks, preemptive computing may be used to design system centrality, scheduling of resources and first-option decision-making (Boussinot, 2006). How to translate such principles for design and planning, and what value does it bring to collaborative challenges in computation?

This paper introduces an interdisciplinary study on 1) democratising preemption for design production, giving deep considerations to current, emerging socio-economic and computational ideas; 2) differentiating preemption beyond prediction to anticipatory actions coming from speculations; and 3) entangling ‘preemption against less desirable futures’ with ‘speculation on the multiplicity of futures’. The speculative shares similar traits with its actionary counterpart - the preemptive - in various disciplines, from speculative realism to speculative financing; there is an emphasis on how information is being used to map alternative future(s), identifying or imagining futures from the opponents’ perspectives (Higgins & Connell, 2019). Along these lines, a critical rethink on the notion of ‘information’ cannot be escaped: its value and utility in relation to the tools that operate it, especially in the development and differing understanding of entropy, which built the relationship between information and energy and ways in which we may describe the state of any system using mathematics as a universal language. By mapping a timeline of events around entropy, this paper hopes to prompt discussions on the future role(s) of information, especially in the collaboration and communication within computational design production.

2. A Historiography of Entropy

Information can be used in many different ways in many different contexts; most notably, it can be defined as entropy or negentropy (i.e. negative entropy), and the differing definition affects the ways in which we think about and use information in design and planning (Shannon, 1948; Wiener, 1948). Entropy is the measure of probable surprises and disorder; whereas negentropy is the minimisation of entropy (Schrodinger, 1944). This measure is the foundation to which all digital signal processing and communication technologies operate on - from digital images, video conferencing, big data analytics to machine learning.

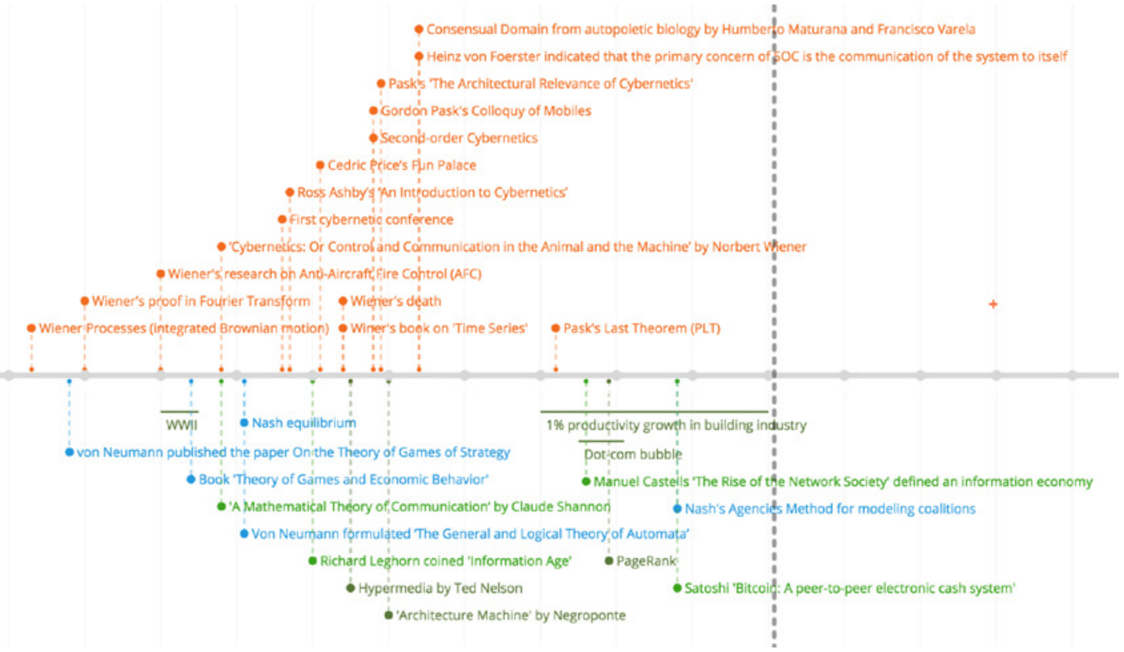


Fig. 2. Tracing a timeline of events around cybernetics and information theories (Ng, 2021).

2.1 Information Compression, Reconstruction, and Intelligence

Two of the greatest science figures in the 20th century related information to entropy differently. Claude Shannon and Norbert Wiener - respectively the father of information and cybernetics theories - were both involved in WWII Anti-aircraft fire control (AFC) research: the art of shooting the opponent's aircrafts down (Galison, 1994). Shannon (1948) was dedicated to the communication of information, whereby the fewer 'bits' you need to use to retrieve a piece of information, the better the wartime communication - Shannon's entropy - the limit to a lossless compression. Whereas Wiener (1942) was working on unifying the engineering disciplines of communication with control, looking into signal processing in a time series - compression in time operations.

Compression exploits the redundancy or the lack of surprises in data to reduce the size in data representation. This caused significant savings in the length of transmission - the better one can compress, the faster one is able to send information back and forth to communicate, but what does 'better' in compression mean? The challenge lies not only in the act of compressing, but reconstructing from the compressed. How can the sender compress messages in a way that the targeted receiver can reconstruct the information contained to precision? For instance, if one is on Zoom, can the signals be compressed in a way that the video will be reconstructed on the receiver's end in real-time, looking almost no difference in quality to the human eye as before the compression? From such examples, one can tell that the problem of compression extends beyond simple technical engineering, to the '*control and communication in the animal and the machine*' (Wiener, 1948). There is a need to understand not just the observed system, but also the observer to the system - human-machine interaction.

According to Shannon (1948), an increase in entropy is an increase in the amount of probable arrangements in a system - an increase in the amount of information, where lossless compression and bandwidth are values. If one can figure out the redundancy in some data (e.g. the repetitive units in data), one can eliminate them to achieve downsizing. Such 'lossless' compression is the systemic limit to which Shannon was questioning - a measure of maximum compression, a measure of entropy. This was much inspired, as Shannon (1948) had acknowledged, by Wiener's (1942) work on extrapolation and interpolation - one of the reasons why Wiener is being named as '*one of the founders of the field of artificial intelligence*' (AI) by MIT (n.d.).

Wiener and Shannon were both hired as research assistants to study one of the most rapidly used computing devices at the time - the differential analyser (Guizzo, 2003). The inventor of this particular analyser is Prof. Vannevar Bush, who was the chairman of National Defence Research Committee (NDRC). During the war, Wiener (1940) sent some of his marvellous ideas to Bush in a memorandum, explaining that the analyser can only do general differential equations, but not partial, meaning that the machine can only work in one dimension, namely time, but not in 2 or more dimensions. Wiener recognized '*discretizing the data over a grid and then averaging [...] by a line-by-line scanning of the grid [...] and that the data had to be represented digitally rather than intensively*'; such convolutional thinking is very much present in today's neural networks (Masani, et al., 1987). On the other hand, Wiener (1948) stated that the machine should do arithmetic by making choices on the basis of previous choices according to a schedule furnished to the machine - a memory based on feedback loop; such formulation of an ideological automated computing machine, a logical machine, much resembles a human. Wiener received a response that his idea was not immediate enough to have been effective in the war (Mindell, et al., 2002). According to the mechanical computing logic of its time, infinite memory is not possible in a finite space; thus, some had held that a universal calculating machine - or a universal Turing (1936) machine - would not be possible given our physical constraints (Borel, 1913). **This highlights the significance of entropy, probability, and compression - the critical measures concerning the limits to synthetic intelligences and constraining the boundary to all signal processing research** - so that no one would spend half their lifetime trying to run an algorithm that simply does not satisfy Shannon's entropy limit. This also set the foundation for Chaitin's (1977; 1994) Algorithmic Information Theory (AIT), one of the founding fields of AI that concerns itself with the shortest computational means to express the largest amount of information - it 'is the result of putting Shannon's information theory and Turing's computability theory into a cocktail shaker and shaking vigorously'.

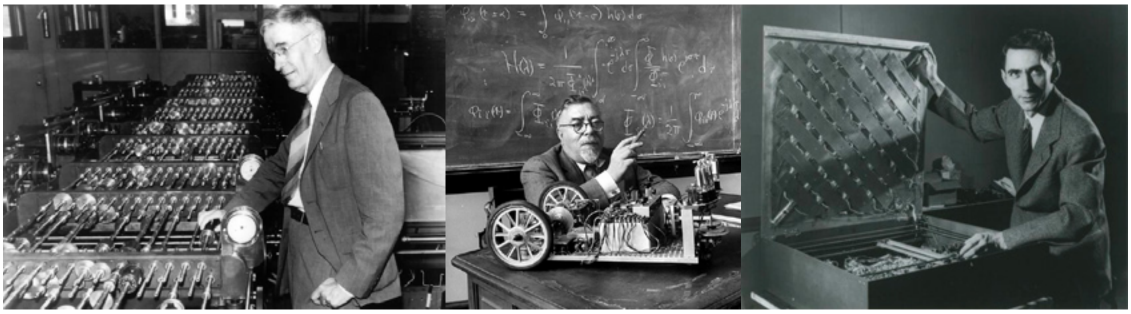


Fig. 3. Vannevar Bush next to a differential analyser in the early 1930s, Norbert Wiener next to his moth robot based on circular feedback in 1949, and Claude Shannon next to his learning machine Theseus in 1952. Image source: Computer History Museum, Cybernetic Zoo, MIT Technology Review.

2.2 Information Entropy, Energy Entropy, and Design as Decision-making

> *'the moment high power circuits are used to transmit patterns or control the temporal behaviour of machines, electrical engineering differs from communications engineering only in the energy levels involved and applicable to such energy levels, but in reality [...]* ***not a separate branch of engineering from communications.'*** - Wiener (1942) Extrapolation, Interpolation and Smoothing of Stationary Time Series

While information entropy measures the limits to synthetic intelligences, a negentropy approach to information relates a system to its larger environment, taking a perspective from outside the system. Wiener (1950) shared a belief with Schrodinger (1944) that within a world which always decays into chaos, living beings always strive to minimise entropy through the creation of information, as exemplified by the incremental thought experiment 'Maxwell's (1871) demon' , correlating information entropy to energy entropy. Meanwhile, Einstein (1905) proved the existence of atoms using Brownian motion, and Schordinger was invested to question why physicists were able to explain a lot of things that happen at the very large scale, like astronomy, but are not able to understand things that happen at the electromagnetic scale, like socio-biology, and to the atomic scale, the quantum mechanics; most importantly, understanding across scales. Schrodinger suggested a ‘naive physicist approach’- while not every phenomena can be understood through their causal relationships, instead, they may be understood by their correlations. He stated that *‘physical laws rest on atomic statistics and are therefore only approximate, and their precision is based on the large numbers of atoms intervening’*. Thus, our physical laws at the macro-scale are actually just an approximation of what is happening at the micro-scale. This is a formulation for the study of complex systems by their correlation.

Schrodinger (1944) described this as the ‘discontinuity of mutations’, and he moved on to stating a ‘remarkable general conclusion’: the collapse of possibilities produces order. But what does order mean? According to the second law of thermodynamics, the level of disorder of any isolated system always increases. If we imagine a system of gas without any external input of energy to hold the molecules together, molecules naturally dissipate and sparse out. The measure of the amount of unavailable energy to do useful work is a measure of entropy. Looking at sociobiological systems like our body, it doesn’t simply disintegrate when it’s living, Schrodinger concluded that *‘[living beings] feeds on “negative entropy” [...] evades the decay to equilibrium [...] organisation [is] maintained by extracting “order” from the environment’* - the export of entropy, the minimisation of disorder or ‘free energy’.

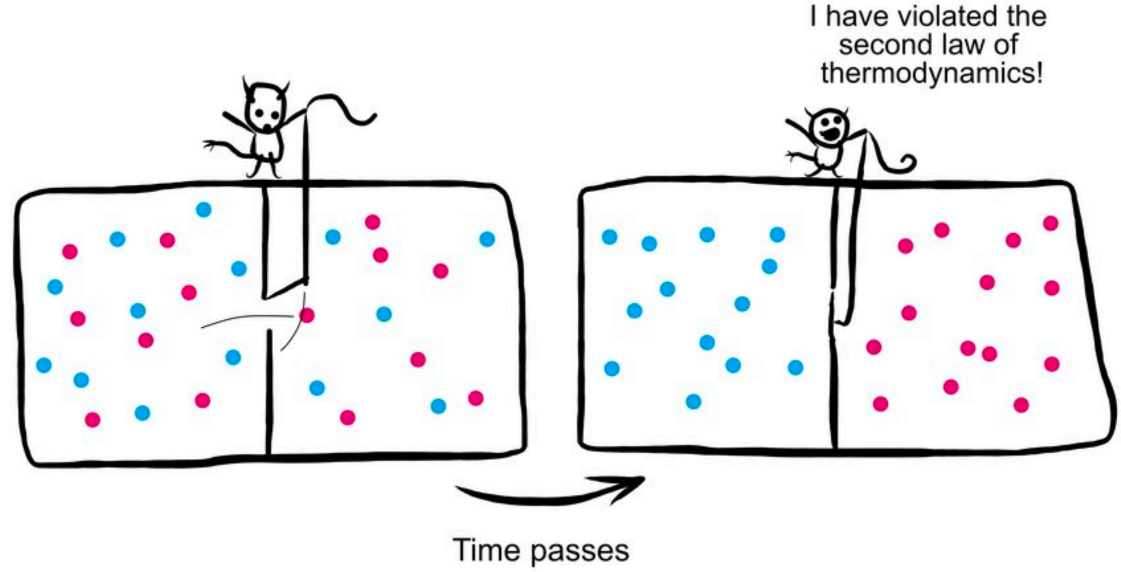


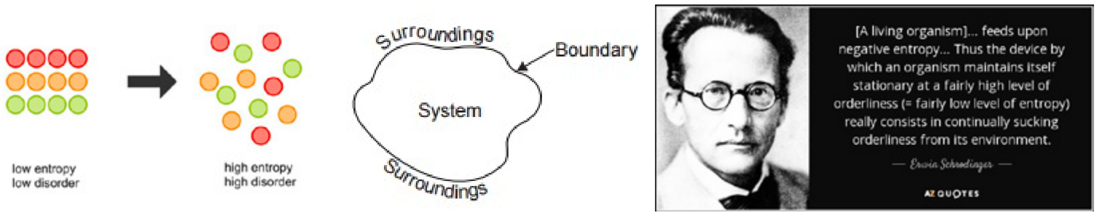
Fig. 4. An illustration of Maxwell’s Demon. Image source: Alyssa Adams.

In the context of design, order does not necessarily imply a cartesian grid, but **the extraction of information - a statistical boundary to a system: to first measure the amount of possible arrangements in the state of a system, to first approximate how much isn’t being known, to first design a measure of uncertainty.** Schrodinger (1944) put it very poetically *‘much more important for* *us here is the bearing on the statistical concept of order and disorder’* - a *‘statistical meaning of entropy’*.

$$S = k_b \ln \Omega$$

S = entropy
k_b = Boltzmann constant
$\ln$ = natural logarithm
Ω = number of microscopic configurations

In Schrodinger’s (1944) ‘entropy = k log D’, K is a constant, D is a quantitative measure of the disorder of a system; the logarithm of D increases with D. The left side to the formula is the macroscopic observation of a system; the right side is ‘*the microscopic view based on the rigorous treatment of a large ensemble of microstates*’. In 5 symbols, the equation provides a descriptive linkage between macro and micro - a means for us to comprehend across scales. Understanding the entropy of a system enables us to derive how much energy we have to input to a system in order to achieve a desirable state; identifying the means of input and describing the evolving state of a system is the act of design as decision-making, providing us a means to correlate information with energy.



[A living organism]... feeds upon negative entropy... Thus the device by which an organism maintains itself stationary at a fairly high level of orderliness (= fairly low level of entropy) really consists in continually sucking orderliness from its environment.
— Erwin Schrodinger —

Fig. 5. Schrodinger’s (1944) formulation of how living beings, different to other forms of thermodynamic systems, are negentropic. Image source: AZ Quotes, OER Commons, Adobe Stock.

2.3 Interpolation, Extrapolation, and Choices

In the matter of extracting statistical boundaries, Wiener (1950) mapped the extent to decision-making within time series, which are ‘*sequences, discrete or continuous, of quantitative data assigned to specific moments in time and studied with respect to the statistics of their distribution in time [...t]he closing price of wheat at Chicago, tabulated by days, is a simple time series*’. This forms a feedback loop between the statistical computation of matter and its material manifestations.

> *‘The fields of statistical practice in which time series emerge can be broadly divided into two categories: statistics of economic, sociological, and short-term biological data on the one hand; and statistics of astronomical, me-*

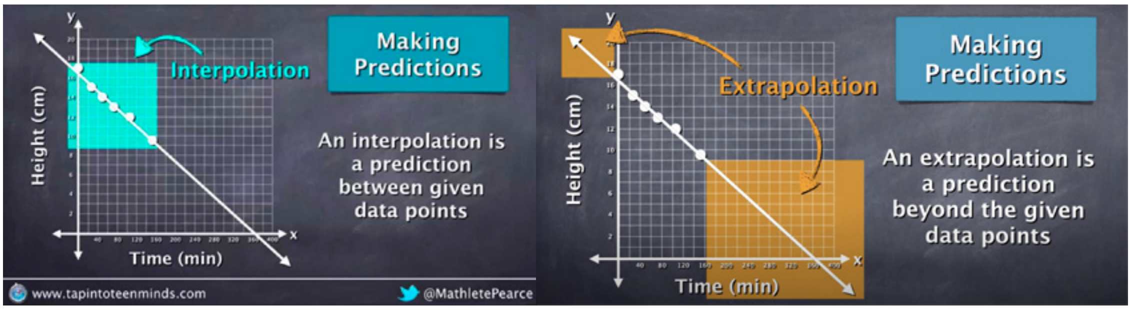
> *teorological, geophysical, and physical data on the other.'* - Wiener (1950) Human Use of Human Beings

Wiener categorises time series into short-runs and long-runs. The former '*forbid the drawing of conclusions involving [...variables...] at a distant future time to any high degree of precision*'. The overall system goal is to be able to draw some sort of reasonable expectation for actions to be taken to have an advantage on proximate conditions based on short-run fluctuations, as in speculative financing. The latter is typified by '*long runs of accurate data taken under substantially uniform external conditions*'; in such cases, the question of design lies in taking data collection as a 'rule' rather than an 'exception'.

Discreteness and continuity in a set of data depends upon whether the sampling is a rule or an exception. A discrete time series is when observations are taken only at specific times (e.g. when a user logs in); a continuous time series is when observations are made continuously through time (e.g. Brownian motion as described by the Wiener process) (Li, 2013). The drawing of a simple function based on discrete data points is an interpolation, which can act as a datum to measure disorder or deviations in a system for purposes of entropy. Concurrently, an extended estimation or projections into proximate futures are extrapolations, much used in iterative interior reconstruction of digital imaging, often combined with a priori knowledge acting as datum or an information seed (Ruchala, et al., 2002; McGlamery, 1973). The compression question of whether data points can be approximated as continuous, smooth, or possibly periodic helps to minimise uncertainty of a system by prediction - negentropy.

> *'The message itself is a pattern and organisation. In fact, a set of messages can be thought of as having entropy, just like a set of states in the outside world. Just as entropy is a measure of disorganisation, the information carried by a set of messages is a measure of organisation. In fact, the information carried by a message can be interpreted as the negative of its entropy, and the negative log of its probability.* ***That is, the more likely a message is, the less information it provides*** *[...]* ***This amount of information is a quantity that differs from entropy only by its algebraic notation and a possible numerical factor.'*** - Wiener (1950) Human Use of Human Beings

To Wiener, information is negative entropy; prediction of less probable events yields more information (e.g. floods); whereas Shannon's entropy holds that the prediction of more likely events yields more information (e.g. weather reports). The socioeconomic value of (neg)entropy might be reflected in Shannon's (1948) use of the word 'choice' - '*can we find a measure of how much "choice" is involved in the selection of the event or of how uncertain we* *are of the outcome?'* - information is measured relative to the amount of choices within a stochastic process. Put simply, compression doesn't mean less choice, but through interactions at the horizon of system boundaries, which mediate between an individual and its environment, the amount of choices become more apparent. **To Shannon's entropy, the ability to predict the likeliness or increasing the amount of choices of one's environment - complex systems that are chaotic and dynamic in nature - becomes one's freedom.** Whereas Wiener (1942) gave the example of '*policy questions [which] do not appear so generally [as in the case of long-run geophysical data,] the effect of a change of policy on the statistical character of the time series assume much importance*', like in short-run socioeconomic or biological data; nonetheless, '*the problem of flood control will show [...] the distinction between the two types of statistical work is not perfectly sharp*', especially in our big data epoch. **For Wiener's negentropy, if one can predict and preempt one's opponent's choices better than the opponent, it secures one's freedom, given that one has the capacity to influence decisions.**



Making Predictions

An interpolation is a prediction between given data points

Making Predictions

An extrapolation is a prediction beyond the given data points

Fig. 6. Prediction with interpolation and extrapolation. Image source: Mathlate Pearce.

The computational history of preemption cannot escape mentioning John Von Neumann - one of the most all-rounded, interdisciplinary scientists and mathematicians of the twentieth century - father of *Game Theory* and *von Neumann Architecture*, and a major contributor to the *Manhattan Project* (1928; 1945; 1945b). Von Neumann was a strong supporter of 'preventive war' - a form of preemption. Amongst which, the Manhattan Project and the invention of the atomic bomb is one of the most significant preemptive games in modern history, where he did '*crucial calculations on the implosion design of the atomic bomb [...his] mathematical models were also used to plan out the path the bombers carrying the bombs would take to minimize their chances of being shot down*' (Standford.edu, n.d.).

Game Theory is the mathematical approach to describing and conceiving dynamics between competing players, largely applied in fields of sociology, economics, politics and warfare (Morgenstern & von Neumann, 1944). Whereas the von Neumann Architecture is the principle model for the modern formulation of Central Processing Units (CPU) and digital computers. These two pieces of scientific discoveries advanced the simulation of interactions amongst rational decision-makers within a game, and were made scalable to geopolitical situations, including the mathematical modelling of the '*Cold War interaction between the U.S. and the USSR, viewing them as two players in a zero-sum game*' (Stanford.edu, n.d.). Together, Game Theory, CPUs, and atomic bombs gave rise to the transcendence of conflicts from hot to cold, from the physical to the mathematical, and threats of mutual destruction from the analogue to digital domains. The race for preemptive design is as much about the advancement of reality and the simulations of those realities. Ever since the Cold War, our computational universe is shown to be one of von Neumann's and Shannon's rather than Wiener's; it is not until today, with advancements of AI and Web2.0, that we once again revisit the wonders of cybernetics.

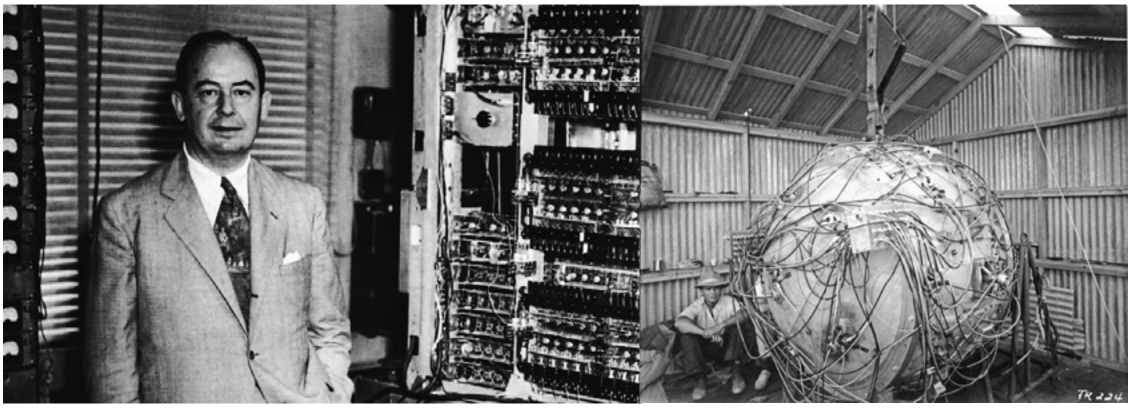


Fig. 7. John von Neumann, who is a strong supporter of 'preventive war', next to an electronic computer in 1945; first nuclear bomb in 1945; Game Theory modelling of Cold War; von Neumann Architecture. Image source: Sothebys, Kapooht, Cornell University, Michigan State University.

3. Preemptive, Speculative, and (Neg)entropy Design

3.1 Neg/entropy Design

Shannon was indeed a former student of Wiener, both of whom based their hypothesis of communication theories on prediction and probability distribution (Mindell, et al., 2002). Wiener (1942) quantified information from another perspective - from the time domain to the frequency domain in a time series, making it easier to zero out insignificant data with simple point calculations, compressing time for prediction. Most notably, Wiener (1933) contributed to Fourier Transform (FT) and Brownian motion, where the time relationships are summarised by the notion of a state that evolves over time according to some probability distribution. Knowing the state and the entropy measure of a system at any point in time not only provides a good description of the system at that time, but it does seem to capture the critical information we need in order to answer questions about the future evolution of the system (Ng, 2021). **This led to Wiener and Shannon's similar worldviews, which differ merely by an algebraic sign - information = +/- entropy.**

The design implications of Wiener's negentropic world view is that our environment contains no information, but information is always the construct of living beings or intelligences. To Wiener, the more information that can be derived from a system, the less surprises there are, the less entropy, the more likely one can predict the opponent’s moves to preempt (e.g. hit one’s target in the war). Negentropic design can be seen as the extraction of order - drawing reasonable expectations from predictions, and the action taken to minimise entropy in a complex system based on information feedback - preemption. Whereas an entropic approach to design can be seen as maximising and measuring the amount of possible arrangements or choices within a system - speculation. In this sense, speculation and preemption work hand-in-hand to maximise and minimise entropy in an information system. Take Generative Adversarial Networks (GANs) and Wave Function Collapse (WFC) as examples: the former utilises a generative model to output options and and a discriminative model to preempt the options until equilibrium; the latter reduces the initial superposition of several eigenstates to a ‘*single eigenstate due to interaction with the external world*’, where the collapsing of possibilities - negentropy - are brought about through the act of observation (Microsoft, n.d.).

According to Schrodinger (1944) large-scale complex systems increase in entropy globally, while minimising entropy locally. Such can be achieved on the edge of a network, much like reflexes on our body’s peripheral nervous system - the system is smart but not necessarily intelligent. **A smart system is a network of sensing, actuation, and control units that is able to react based on raw data. Whereas intelligence is the ability to minimise entropy through the generation of information, and is able to predict, speculate, and preempt.** Maxwell’s (1871) demon is a form of self-organising intelligence that illustrates how any complex system, which utilises information to overcome entropy, should be studied not simply as mechanics but as optics. **While intelligence is able to overcome entropy without applying any work (as defined by thermodynamics), smart is its physical counterpart; the feedback between smart and intelligent systems is the bringing together of analogue and digital computation - the union of Wiener and Shannon’s worlds.**

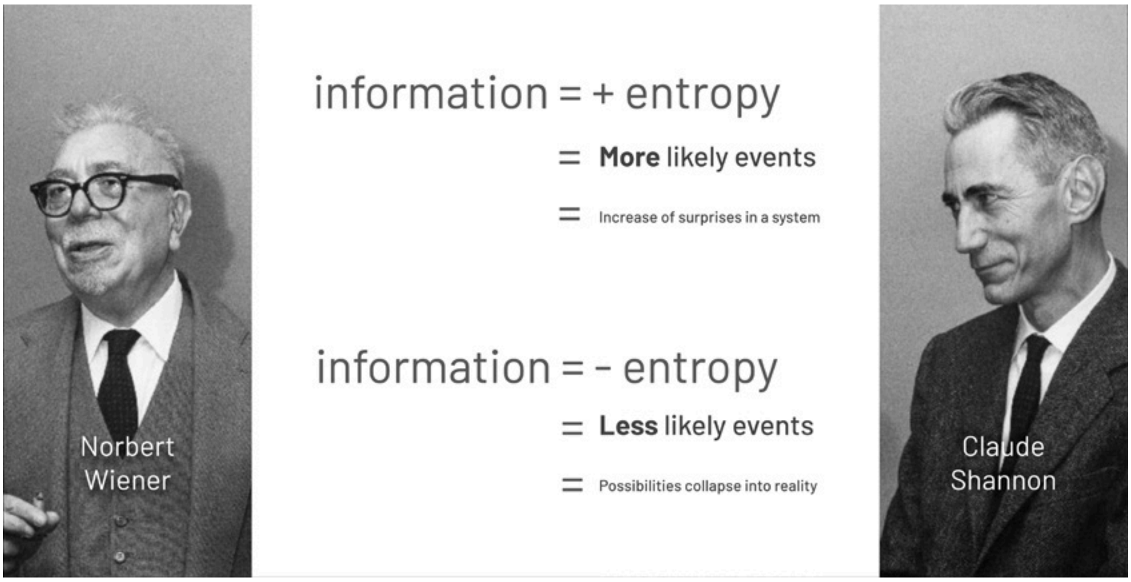


Fig. 8. Wiener and Shannon’s definition of entropy. Image source: MIT Museum, author.

3.2 Speculative Design

Speculative design is the increase in entropy or the maximisation of surprises in a system. It is the investment of resources into assets (tangible or intangible) with the hope of significant gain in the future from short-run and long-run fluctuations, pertaining to substantial risks for the same reason, just as Speculative Financing. It is to build without formal commitment from any end users, just as Speculative Construction. It is the computing of tasks in advance to achieve real-time performance, even though the task may not always be needed, just as Speculative Computing.

Speculative design can be based on fictional communication in constructing a narrative to illustrate and persuade alternative futures, just as Speculative Realism (Robin, 2007). Alternatively, non-fictional speculation is defined here as a ‘naive physicist’s approach’ - Speculative Reasoning. Having learnt the statistical foundation of one’s sciences, social or natural, one begins to think about relevant contributions and the best possible way of asking questions, to humans and computers alike, comparing one’s anticipatory theories with contextual facts (Schrodinger, 1944). In this sense, it is counterintuitive to the trial-and-error approach of most machine learning systems nowadays, but one must not ‘*imitate the iterative methods of the computational tools*’ if one can’t replicate their speed in induction; as Carpo (2017) advocated: ‘*each to its trade; let’s keep for us what we do best*’. Speculation is a human trade, which can be advanced with the help of machine intelligence.

In this sense, speculative design is a proto-scientific approach that studies the ‘*normative criteria for the use of experimental technology*’, with a genuine willingness to be tested for failures in advancing to becoming real sciences, social or natural - Speculative Engineering (Brakel, 2000; Bunge, 1984). For instance, in the field of transistors, many small and medium design firms have the capacity to speculate on the architecture, but only relatively bigger enterprises can prototype for testing due to the high specifications of fabrication. **This exemplifies the general participatory qualities of the speculative, and highlights the significance of collaborative intelligence across scales.** Speculative design can be achieved through intelligent pipelines, datum construction, and information seeding to bootstrap crowd contribution and enable variational output.

3.3 Preemptive Design

Preemptive design is the decrease in entropy or the maximisation of order in a system through anticipatory actions taken based on speculative design. In the case of distributed computing involving a network of autonomous agents - collaborative intelligence - preemptive design is the interpolation and extrapolation based on long and short run statistics in scheduling time and resources. Interpolation is the compression of high-dimensional data into models that act as datum in measuring deviation; extrapolation can be used for prediction and reconstruction of information.

In a distributed network, system capacity rests in the autonomy of each individual component in how they make decisions - with, without, or partial memory. Depending on 1) the size of the system, 2) the amount of agents, 3) the discreteness and continuity of data, 4) the targeted system centrality and 5) scalability, Markov and martingales properties can be used to model system movements and leverage system memory in a large-scale network. Wiener processes spawned the study of continuous time martingales, it's property '*states that the future expectation of a stochastic process is equal to the current value, given all known information about the prior events*'; as opposed to Markov properties, where the future is independent of the past given the present - the '*stochastic process essentially has "no memory"*' (QuantStart, n.d.). These stochastic logics can be applied to preemption within a time-sharing network - many users sharing the computational resources at the same time, where context-switching is based on a scheduler furnished to the machine (Clark, 1965). As Wiener (1950) stated, '*the structure of the machine or of the organism is an index of the performance that may be* ***expected*** *from it*' - prediction can help in estimating the importance of tasks for scheduling, without complete information for scalability in large-scale systems - preemptive computing.

In non-preemptive computing, each agent voluntarily yields control periodically but must cooperate for the scheduling scheme to work; it helps to carry out each task to precision with simpler implementation (Boussinot, 2006). It is often used in memory-constrained embedded systems but rarely deployed in large-scale systems, as each agent has almost complete autonomy, and a 'selfish' agent (e.g. a poorly designed program) may consume all of computing time (PC, n.d.). Whereas in preemptive computing, the scheduler preemptively multitasks without synchronising to all agents all of system memory, but interrupts tasks to resume them at a later stage for purposes of speed, and is much used in real-time computing. Much like the logic of speculative computing that performs tasks, which are not necessarily needed, but may increase overall system efficiency. Take geometry prediction as an example, voxels as discrete data parcels paired with a preemptive scheduler can interrupt the upsampling at any time to distribute computing power amongst several tasks. In such cases, **the system is technically distributed, but not inherently decentralised, where centrality is a matter of design** (Ng, 2021).

4. Conclusion

This paper mapped a timeline of events around cybernetics, information and quantum theories, tying the history of entropy with computation to rethink preemptive and speculative designs. Through theoretical means, this paper aimed to provoke discussion on the role of information in the collaboration between a distributed network of human and machine intelligences - collaborative intelligence. In revisiting Norbert Wiener, Claude Shannon, and Erwin Schrodinger's thinking, this paper first questioned the difference between 'intelligence' and 'smart'. A smart system is a network of sensing, actuation, and control units that is able to react based on raw data, whereas intelligence is the ability to minimise entropy through the generation of information, and is able to predict, speculate, and preempt. Through the notion of algorithmic information theory (AIT) - a combination of Shannon's information theory with Alan Turing's computational theory - entropy is defined as a measure of the computational limits to synthetic intelligence, and negentropy is the minimisation of uncertainty in a system through intelligence.

Wiener defined information as negative entropy (negentropy): the prediction of less likely or anomaly events and the minimisation of uncertainty. Whereas Shannon defined information as positive entropy: the more 'surprises' or disorder, the less repetition, the more information in some messages. Within design, an entropic approach maximises surprises or options in a system - speculative design that seeds ideas, whereas negentropic approach is the design of order through defining statistical boundaries, and when all design possibilities collapse into reality (i.e. implementation or fabrication of design). Wiener and Shannon's differing understanding of information also provokes differing understanding in 1) intelligence, 2) design as decision-making, and 3) choice and freedom within collaborative systems.

Wiener shares a similar worldview with Schrodinger: although energy entropy tends to increase, living beings are the negentropic through the creation of information - intelligence. This shows a means by which designers may describe and capture the immateriality of information and their physical manifestation through our modes of energy exchange, grounding it within the larger socio-economic context. Negentropy is the minimization of uncertainty by prediction, and can take forms of interpolation and extrapolation: the former uses *a priori* knowledge to project into multiple future(s); the latter draws functions through sets of data points to measure expected deviation. While taking into consideration long and short-run statistical works, the overall system increases in entropy on a global scale, while minimising entropy at a local scale. As such, freedom is the prediction of less likely events and the ability in preempting such events.

Shannon's information theory shares a similar worldview with John Von Neumann, who is a major contributor to game theory, the invention of CPUs, and the atomic bomb. Together, these inventions facilitated speculative preemption games within the Cold War, and gave rise to a transcendence of conflict from the physical to the digital domain. As such, freedom is the prediction of the likeliness of an environment, and the maximising of choices and futures in a system - speculative design - and preemption is the lack of reason to change only one's own strategy after predicting the opponent's choices, be it natural or artificial opponents. The value of speculative design is the anticipatory action taken through design preemption, and vice versa - speculative and preemptive designs inform one another.

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