ActInf Livestream #040 ~ 'A free energy principle for generic quantum systems'

A three-session series of discussions of the paper "A free energy principle for generic quantum
Chris Fields, Karl Friston, James F. Glazebrook, Michael Levin
https://arxiv.org/abs/2112.15242

Presented by Active Inference Institute

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LS #40.0: Background and context. https://youtu.be/-qZYxSbJ38E
LS #040.1: First participatory group discussion. https://youtu.be/NkJKl_yF274
LS #040.2: Second participatory group discussion. https://youtu.be/Cgo-0UU848M

#40.0

March 10, 2022

[section: Introduction]

00:04 [Music]

[sp: Friedman]
00:28 All right! Hello and welcome. This is ActInfLab Livestream number 40.0. It's

00:34 March 10th 2022. Welcome to the ActInfLab. We're a
00:41 participatory online lab that is communicating, learning, and practicing applied Active Inference.
00:47 You can find us
00:48 at the links here on the slide. This is recorded in an archived live stream, so please provide us with
00:54 feedback so that we can improve our work. All backgrounds and perspectives are welcome. And we'll be following video
01:01 etiquette for live streams. Check out activeinference.org to learn more about
01:07 the lab.

01:08 All right! In today's number 40.0 the goal is to
01:16 learn and discuss this very cool paper that was published
01:22 on ArxivArchive on December 30th 2021, "A Free Energy Principle for Generic
01:28 Quantum Systems" (https://arxiv.org/abs/2112.15242) by Chris Fields, Karl Friston, James F. Glazebrook, and Michael
01:34 Levin. And just like every video, it's going to be just a conversation
01:40 going over some parts of the paper. It's not a review or a final word.
01:45 And if anything it's {um} a cry for help - or at least a cry for participation, because there's so many areas where
01:51 somebody with different experience or more knowledge about any of these domains could connect some dots or
01:58 give some useful comments or critiques - so especially with this video -
02:04 though Bleu and I had help from our colleague Jason Larkin with many of the
02:09 details. There's just so much to unpack! So we'll try to make this a
02:15 useful dot zero.

02:16 And then we're really looking forward to the dot one and
02:21 dot two and so on, when we'll be able to really go into some of these directions.
02:26 So I hope if you're watching live, or between now and the dot one,
02:32 check out the paper and listen to this discussion that we'll have now and ask some questions. Because this is just
02:40 the beginning of a few new threads - probably more than the answering of questions, especially to any desired
02:47 level of {like} completeness or applicability. So it's just the beginning - that's what the dot zero is about.
02:48 It's "a
02:52 new decade," 40.0.

02:54 So {um} we'll just {uh} introduce yourself and
02:59 then go through a bunch of the paper. And, yeah, thanks again to Jason for a lot
03:04 of help, and Bleu for awesome work on the slides, too. {okay so}

03:10 {um} I'm Daniel. I'm a researcher in California. And I'll pass to Bleu as

03:15   facilitator.

[sp: knight]
03:17   I'm Bleu Knight. I'm a researcher in New Mexico. And I have to shout out to Daniel
03:22   too, because you're always saying "thank you" to me - but, you know, we all have to say "thank you" to you, for providing the affordances to be here and {you know}
03:28   discuss these awesome questions. {um} big paper! I am {uh} excited to delve into this!
03:33   I think it will {you know} start a lot of new trails, {so, I think} {um} and also to bring back Mike Levin and to
03:41   bring back Chris Fields {um} and to bring back Karl Friston, back to the ActInfLab, to discuss the dot one with us, hopefully.

03:49   {um} okay! So is there anything particular that you are excited about Daniel? Or do you want to just power through it?

[sp: Friedman]
03:59   Let's
03:56   {get let's} jump in

[section: Why should we model Quantum Systems with the FEP?]

[sp: Knight]
03:58   All right. So this paper really was trying to unite
04:03   {um} the Quantum principles and the Free Energy Principles. So Quantum Mechanics
04:09   and kind of delving into that. And we will see some threads carry over from
04:14   the last time that we had Chris Fields on here. Maybe the last time we had Mike Levin on here also. {um}

04:18   So how is the Free
04:20   Energy Principle related to Quantum Mechanics? What does the FEP gain from quantum? What does Quantum gain from the
04:26   FEP? Are we using the FEP now to model Quantum systems? And why are we pursuing
04:32   this intersection? So this was kind of like the big questions kind of maybe we can start to answer with this paper.
04:41   {um} so we are here. Daniel what's this map about?

[sp: Friedman]
04:46   {um} it's a question we're gonna probably ask ourselves multiple times, so we can insert it like a little emoji,
04:53   but we can think of among the axes of variation, or
04:58   variability that we're going to explore, or where we're going to tune our regime of attention, or what perspectives we're
05:04   going to take, it's going to be {like} along two axes ranging from on the right side FEP
05:10   active {like} to the left side which is {like} pre or non

05:15 active/FEP. That's the x-axis. And the y-axis is the continuum between
05:22 Quantum, which we'll probably nuance and hear many perspectives of what is and isn't Quantum, but just to summarize it
05:28 by saying "Quantum", and not Quantum {like} pre or non-Quantum approaches. And so
05:34 Quantum FEP is in the upper right corner. And we can think of it as being {like}
05:40 connected in different ways to Quantum non-FEP in the top left, the
05:46 blue, and then FEP, but from a non-Quantum perspective {like} all pre now
05:53 FEP Act Inf in green. And then what are all the other connections?
05:58 And so who's right? Who's wrong? Who's useful? Where's their pragmatic value? Where is
06:04 their epistemic value? What are we really talking about? Do we agree on the phenomena?
06:09 Where is their agreement or disagreement? Where are we in this complex landscape?

[sp: Knight]
06:16 So I think in mechanics we refer to it as Classical Mechanics and Quantum
06:22 Mechanics, {so now we will be} this is {like} the dividing point maybe between Classical FEP and Quantum FEP, perhaps.
06:31 Let's see where it goes. So the aims and claims of the paper,
06:39 there are pretty much three, and we'll revisit these at the summary, because we're going to just give you
06:45 a broad overview of the summary of results right now. Given the standard free choice
06:50 assumption the intuitive ideas of an <i>"agent"</i> or <i>"Information Gathering and Using System"</i> (IGUS)
06:57 can be fully formulated within background independent scale-free quantum information theory.
07:04 The second claim is that FEP can be a quantum theoretic formulation that
07:09 renders it applicable to generic quantum systems. And do you want to read the last one Daniel?

[sp: Friedman]
07:15 {uh} three when formulated as a
07:17 generic principle of quantum information theory the <i>FEP is asymptotically equivalent to the Principle of Unitarity</i>.

[sp: Knight]
07:26 Cool. Do you want to read the first section of the abstract?

[section: Abstract]

[sp: Friedman]
07:29 All right. The Free Energy Principle or FEP
07:33 states that under suitable conditions of weak coupling, random dynamical systems
07:39 with sufficient degrees of freedom will behave so as to minimize an upper bound,

07:44   formalized as a variational free energy, on surprisal, also known as, <i>"self-information"</i>.
07:50   This upper bound can be read as a Bayesian prediction error. Equivalently, its negative is a lower
07:57   bound on Bayesian model evidence, also known as <i>"marginal likelihood"</i>. In short,
08:02   certain random dynamical systems evince a certain kind of self-evidencing.

[sp: Knight]
08:11   {so} here, we reformulate the FEP in the formal setting of space-time background-free, scale-free Quantum
08:18   Information theory. We show how generic Quantum systems can be regarded as observers,
08:24   which with the standard freedom of choice assumption become agents capable of assigning semantics to observational
08:31   outcomes. We show how such agents minimize Bayesian prediction error in environments characterized by
08:37   uncertainty, insufficient learning, and quantum contextuality, we show that in its quantum-theoretic
08:44   formulation the <i>FEP is asymptotically equivalent to the Principle of Unitarity</i>.
08:49   Based on these results we suggest that biological systems employ quantum coherence as a computational resource
08:56   and <i>implicitly</i> as a communication resource. We summarize a number of problems for
09:01   future research, particularly involving the resources required for classical
09:07   communication and for detecting and responding to quantum context switches

[sp: Friedman]
09:14   It's like okay cool. What does it mean? How will it be useful?

[section: Roadmap]

[sp :Knight]
09:23   Yeah {um} so we're gonna unpack a lot of this and hopefully give everyone a good framework with which to {kind of} go
09:30   forward into the dot one and dot two maybe a little bit of background understanding. {um} the paper is very beefy.
09:36   So we'll do our best to {kind of} lay the framework down. They give us a good road map. So there's
09:44   five sections: 1) Introduction, 2) Physical Interaction as Information Exchange and several subsections within
09:50   that, 3) Repeated Measurements and System Identification and subsections, 4) {the} "FEP
09:56   for Generic Quantum Systems."and 5) {the} Discussion. And I think that they actually

outline
10:02   what's in each section so we'll give you that outline overview as we go through the paper as well.

[section: The contextual thread]
10:11   So {just we're going to use} we're going to actually reuse some slides from ActInf
10:16   Stream number 17. That was when we had Chris Fields presenting information flow in context
10:22   dependent hierarchical Bayesian inference. I think contextuality is like an underlying thread that's pretty
10:28   important here today. So Chris kind of lays that out in the {um} in that paper.
10:34   And so if you want to get into that and dive deeper into **Chu spaces** and
10:40   Channel Theory which we'll talk about a little bit but {um} yeah. That's there. So use that for a
10:45   resource.

[sp: Friedman]
10:47   Just one foreshadowing here, the two pieces that they claimed in this
10:53   paper as their goals was to connect contextuality to Category Theory
10:59   and Chu Spaces and then connect that yellow formulation to hierarchical Bayesian inference
11:07   more looking like the statistical models. And so this paper is {kind of} building a category theory bridge with Bayesian
11:14   graphs and statistics, and Category Theory. And then that's probably going to hinge over to a few other areas.

[section: Introduction]

[sp: Knight]
11:25   Cool! So we can jump right into the introduction {um} here. And we're just going to highlight
11:30   some keywords as we go through. The authors didn't really give keywords for the paper, {um} which I'm kind of grateful
11:36   for because there's {so much} so many other things to unpack here. So they {um}
11:41   highlight some things about the FEP. In the words of the authors, "Since its introduction as a theory of
11:47   brain function, the variational Free Energy Principle has been extended into an explanatory framework for systems at
11:54   all scales.... The FEP is the statement that any measurable bounded and macroscopically
12:00   system will behave to satisfy these requirements". {requirements} what else Daniel?

[sp: Friedman]
12:09   It was just cool. How they brought in the FEP as being the overarching level, as

12:17 describing how these particles do two things which is possess internal
12:23 dynamics that are conditionally independent from the environment, and performing this self-evidencing
12:30 feature by returning to some non-equilibrium steady state (NESS). And so {just} which parts of
12:36 the FEP they entered in at, or emphasized, which we can assume are
12:41 setting the stage up in their mind best for the interfacing or the on-ramping
12:47 into quantum, where somebody interested in like a system or integration other than quantum
12:53 might take a different approach.

[sp: Knight]
12:57 Cool! I think that they borrow also from
12:59 our particular physics, and we're going to talk about particles -- and they talk more about particles in the discussion,
13:06 and maybe we can have a deeper conversation about those in the dot one and dot two -- but they say the Markov boundary of any "particle" --
13:13 {um} that is, an open exchange with external states via its Markov boundary -- underwrites conditional independence
13:19 between its internal states and the external states of its environment by localizing and thereby restricting
13:25 information exchange. So the Markov boundary separates internal and external states by
13:31 mediating their exchange. We've seen that before.
13:38 Cool. So what is Active Inference Daniel? Can you break it down for us? Two sentence overview?

[sp: Friedman]
13:43 That blanket that Bleu just described with the insulation, incoming statistical dependencies can be
13:50 interpreted as perception. And outgoing statistical dependencies can be interpreted as control.
13:57 And depending on the situation, {and} what's zero, {and} what's not zero, that can
14:02 have a lot of dynamics that are similar to some other classic settings in decision making,
14:09 gambling, experimentation, quantum measurement
14:15 in this paper.

[sp: Knight]
14:17 Very cool
14:20 {uh} so what is quantum theory? {um} this is cool. Just some pictures, and it's
14:26 connected {in} to many many different {uh} fields. So there's a cool {kind of} concept map of
14:33 where quantum theory intersects. {um} but {you know} the quantum theory here is the idea that {that}

14:40   all physical systems, {can} including the environment, can be considered observers that act on their surroundings to
14:46   prepare them for subsequent observations. That's become common in quantum theory,
14:51   replacing the wave function collapse postulate of traditional quantum mechanics with interaction induced
14:58   decoherence, which is {like} the dissipation of quantum coherence, {this is
15:03   like} the thing that generates classical information. And they say "Indeed while quantum theory
15:08   was originally developed -- and it's still widely regarded as the theory specifically applicable at the atomic
15:14   scale and below -- since the work of Wheeler, Feynman, and Deustch,
15:20   it has, over the past few decades, been reformulated as a scale-free information theory and is {increased} increasingly
15:26   viewed as a theory of the process of observation itself." {so um yeah I think like} when we think
15:34   about quantum, we think about the observer, at least I do, {like I think} about the observer phenomenon. Just the act of observing a system changes the
15:41   system. So that's {kind of} a fundamental thing that comes to my mind. What comes to your mind Daniel when you think about quantum
15:47   theory?

[sp: Friedman]
15:48   {uh if} reading that leaves me uncertain
15:53   whether we're talking about {like} organic chemistry, and the pi orbitals, and covalent bonding, and emission, and all of
16:00   those things that particles do -- which is what it sounds like they're talking about in this orange part,
16:06   "a theory specifically applicable to the atomic scale and below". And then this blue part makes it sound
16:13   like they're opening it up into a much larger space. So I think we'll probably
16:19   learn a lot about that. What does quantum mean here? Are we talking about electrons
16:24   and protons? Or is this something that is like Bayesian Inference, in that it's scale
16:31   free, or scale a priori, or scale friendly, or something like that.

[section: Physical Interaction as Information Exchange]

[sp: Knight]
16:38   Nice! Scale independence... So we're gonna jump right in. So section
16:43   two they talk a lot about "Physical Interaction as Information Exchange" and that's something I wonder also -- {like is
16:50   you know} we have {the} classical mechanics. And do the laws of quantum always apply? Or at some scale are they {you know} not
16:56   applicable? Or can we extend them into some {like} theory of everything? {like} are we getting there?

17:02 Maybe. But here in this section they say {that} they "use the category-theoretic
17:08 formalism of Channel Theory to formalize the operational semantics of natural languages." So they develop a
17:15 generic formal representation of quantum reference frames, and show how the
17:20 non-commutativity of quantum reference frames induces quantum contextuality. {and}
17:26 I had fun really digging into this at a level that I felt comfortable explaining it.
17:32 So I'm excited to see {if I} if I bungle it or how it goes. Let's see.

[sp: Friedman]
17:38 Okay, what is quantum?

[sp: Knight]
17:39 Wow! When physical interaction is used
17:43 information exchange "why is it quantum?" becomes obvious: the fundamental {quantum} quantum of information is one bit, one
17:50 unit of entropy, that one system exchanges for another. So one bit, one quantum of information, is
17:57 the answer to one yes or no question. That is quantum.
18:03 Do you want to add anything here Daniel?

[sp: Friedman]
18:08 This is the block text {is} from
18:11 the paper, and {just} one piece that will be interesting to
18:17 explore is {just} "how does time and temperature come together?"
18:24 {like} I had {just} heard, or thought more about the space required for storage and
18:30 not really seen it as much connected to the speed of obtaining
18:37 that yes or no answer at different temperatures, and what that might mean for
18:44 biological or for digital systems.
18:50 But I'm sure that's a {very} {um} foregone conclusion maybe working with a
18:55 quantum device, but new to me. And Jason was like, "oh yeah of course that's the case"

[sp: Knight]
19:02 And {they they talk a lot so} foreshadowing they're gonna {um you know really} present this within like a space-time independent context which is
19:10 kind of cool. And then {like} link it back to time which {that kind of} gets a little interesting.
19:16 All right. So,
19:21 moving on {uh} hilbert spaces {um}
19:27 so Daniel do you want to say a bunch about this? Or what do you want to say about
19:32 this? And then I'm going to highlight some stuff.

[sp: Daniel]
19:36 I'll just read what they
19:39 {um} wrote. Oh, {here's the} the red part {is} was our
19:44 comments on what they wrote. People can pause it to read what they wrote. The hilbert

spaces contain all states
19:50 described as a vector. And this is one way that qubits are
19:55 constructed: by relating two levels of a system, like
20:02 electrons in a ground or excited superposition and then the collapse
20:08 into one or those other bands. And so that's more of {like} a
20:14 uncertainty to discrete transition, but then in the limit of high temperature there's a lot of blur
20:21 or experimental factors that can be modeled as blur that results in a smoother distribution
20:27 of outcomes. And
20:33 here this hilbert space is describing how the experiment is set
20:39 up and the information that's being modeled at a given time.
20:45 So the state of {that} this space consists of the options for
20:50 is {like} the {just the} experiments space, including the total target system and the observer.
21:00 Maybe... [laughter]

[sp: Knight]
21:03 {so} I like this quote at the end, {that} as
21:05 Fuchs put it, "Infinite dimensional Hilbert spaces are from an information perspective merely a
21:10 'useful artifice' permitting computation with differential equations". And {they} they contain all {this} the
21:16 possible states in an experiment as vectors. So {um}
21:21 there's more to read about that. {um} And also the mathematical notation if you're curious
21:27 about kets and bras and some of these brackets that we had to to dig through to
21:33 find solid ground. {yeah Okay} So the Principle of Unitarity
21:40 is the principle that observable information like energy is neither created nor destroyed by physical
21:46 processes. And I thought that this was interesting: {so} time reversal symmetry
21:52 is essential for the conservation of information. So a system is time reversal symmetric
21:57 if its equations of motion allow perfect prediction of the starting point based on knowing
22:03 the state of the system at any given time. So {like} if you know at time whatever, x time
22:09 steps, you can still say something about the starting system, because you can run it forward and
22:15 backward in time. {I mean} There were some cool things like about, if you pulled up a mirror {that's} that's {like} enables the
22:21 time reversal. So some things go forward but {like} the spin of an electron is spun backwards in time. [laughter] right? So it's {like}
22:27 those kinds of things {um} {like} {are} some things are parallel and some things are opposite in time
22:33 reversal symmetry, but {um} anyway. I thought that was interesting and fundamental. So

kind of the Principle of
22:39 {an} Unitarity and also because we're going to talk about time in a cool way I think.
22:45 {um} Okay - so -
22:51 yeah unitarity!. [Laughter] What do you want to say about Unitarity, Daniel? I said a little bit so let me
22:57 pick out some things here that you want to talk about.

[sp: Friedman]
23:00 Okay. This was all with {just} Jason helping us. And again, it's {like} an opportunity for anyone who's familiar with these {to} formalisms to help us a little bit more through. But just to pick up on one point, {just} as Bleu mentioned, {like} we're doing experiments where it doesn't matter what time we started at, in a sense, {like} it may matter in the sense that the different times lead to different results.

[sp: Friedman]
23:27 But a statistical framework for observation that can cut through some of the parts of the experimental context that are not relevant to compare different events that happen at different time in a unified statistical framework. And so that was what led to this principle of unitarity, that the total probability distribution is preserved with {like} a mass of one so that there can be information evolution, but it's happening in a certain space where there are {a} certain invariants that allows useful computation to happen.

[sp: Knight]
24:08 Cool! Conservation of probability. So that's something that maybe came up- {like} the probability that a particle is somewhere- {like} it's somewhere- there's 100% probability that the particle is somewhere. {so} It didn't disappear. {so} That was another kind of interesting question.
24:24 We were talking before this.
24:28 I mean, that's {kind of what} how you get the conservation of observable
24:32 information as well.
24:36 Okay,
24:38 Separability and
24:40 Holographic Encoding.

[sp: Friedman]
24:45 Okay. This one, just to briefly look at a previous slide, I think this was from 32. We were looking at sparsely coupled systems from a matrix perspective. And so the dense coupling of {like} sub units one through six with each other was mainly {like} within the click of the red or the blue. But then there's these off diagonals that reflect the sparse coupling of denser clicks.

[sp: Friedman]
25:10 And so in section 2.3 of this paper, they're also talking about coupling patterns in systems, specifically ones that have a separability. So {like} one of those blocks could be the experimental system, the quantum computer, and the other one of the blocks would be the

experiments and then there could be sparse connectivity reflecting the experimental apparatus, but that was being approached from a quantum holographic angle, also setting up for a Markov blanket take.

[sp: Knight]
25:47 {Cool} {So} One sentence on this page that I think is important is underlined here. “The entanglement entropy is a mutual information measure that detects quantum correlation of coherence between A and B.” And {so} that defines separability and either a system is separable or it's entangled. So separable states are also called decoherent, and entangled states are also called coherent.
26:17 {so} Just to point out as we go forward, and kind of dive a little bit deeper into the math.

[sp: Friedman]
26:23 It's kind of like if it was parametric classical statistics, we would say uncorrelated or correlated. If it was information theory, we'd say no information or yes, it gives information. Bayesian graph, yes, it has causal influence or no, it doesn't. And then this is the quantum take. Yes, it's entangled or no, it's not entangled.

[sp: Knight]
26:42 Also, don't forget conditional dependance or conditional independence, but where is it conditionally dependent? {And} We know that {like} the Markov blanket can help to define conditional dependance, when we've looked at active inference in the past.

[sp: Friedman]
26:59 Yea.

[sp: Knight]
27:03 Okay, cool. So where do you want to talk about the Hamiltonian or not at all?

[sp: Friedman]
Nope.

[sp: Knight]
27:08 Or what do you want to say?
27:09 Not at all. Okay

[sp: Friedman]
27:10 Not sure what to say.

[sp: Knight]
27:11 {So the} So there's one cool thing that I want to point out here. We talk about {like} weak interactions, strong interactions, different time frames and how these are going to vary as we go forward. But {but} here I really just wanted to point out that {that} this H of AB is {like} the Hamiltonian. So we're talking about matrices as separability interacting matrices, conditional

dependance just on the last slide.
27:36 And so the interaction between the Hamiltonian of the matrix can be decomposed into this H_{AB} where this is {like} the interaction between A and B, so H_{AB} can be looked at as we go forward as the energetic interaction between matrix A and matrix B, state A, state B, position A, position B, {or} they give it to us in a very generic form.
28:02 So I didn't really know how to apply that going forward. But maybe if the authors were listening, though, they'll come in and rescue us [laughter]. That's the only thing I really wanted to point out {from} from that slide. {And then} This is kind of cool, {So} [laughter] this {this} equation six which we just looked at, which is the energetic interaction between A and B, this is physical interaction, which I guess could be the physical interaction between A and B, that's just the energy right? Matter equals mc squared.
28:32 "Physical interaction" equals "thermodynamics" times "Yes or no questions". So, it's cool the authors say, "This formulation emphasizes what quantum theory is about: the process of obtaining information. Obtaining information from B requires, in particular, that A acts on B by asking questions. As Wheeler puts it, 'No question?' "No answer!' All inference in this framework is active inference; Eq. (6) does not allow passive perception to be a physical process."

[sp: Friedman]
29:03 Super interesting, agreed, from a lot of angles. It almost takes it to a level we haven't seen from just saying, well, perceptual inference, even the generative type- so not just the signal processing- , but even a predictive processing generative framework for perception that doesn't take action into account is incomplete. Hence, the motivation for Active Inference. And this is somehow escalating that into saying that all inference in this framework is Active Inference.
29:37 And I wonder if that's because like a frame is always needed, some kind of generative model's always needed as a recognition model dual for any observation. So if you're in the business of making observations, you're in the business of generative model modification one way or another, or you're not the kind of thing that does either of those, but they might come into play in the minimal actinf entity or the thing that can be modeled as a minimal acting entity.
30:07 And so there's a lot of interesting areas, and I think it's also quite interesting with the natural language equation. So how should we read that dot? "Thermodynamics"- what- yes, no questions. And then
30:21 times or what does it mean?

[sp: Knight]
30:23 Yeah, there's the category theory like that DOT operator, I forget how to read it, so hopefully we'll be.
30:30 rescued. [laughter]
30:32 But yeah, I read it as times because I'm old school. So going back to that same equation six- I thought that this was important. It involves no assumptions about space, time, objects or motions. It is strictly topological: given separability, It identifies a boundary "fancy B" between A and B at which the energy interaction, physical interaction, between A and B is defined.
30:59 {So} I guess that would be {like} a space- Well, I guess it's not space. It's not space, it's

not time. It's a physical- It's an energy interaction. H_{AB}? Anyway. Yeah.
31:09 And this is the Markov blanket “fancy B” holography connection, which is that all the information that is making the sparse connectivity of A and B, we're talking about systems that have like this screen / blanket / experimental apparatus, “fancy B” and the properties of it for system that might be making classical like measurements, or maybe it's making quantum measurements.

[sp: Friedman]
31:39 So implicitly the prior work had been thinking about what was on the other side of that experimental apparatus from a classical or from a non-quantum perspective. We'll see. And this is taking it more into asking what kind of mathematics would be needed to look at it if it were a quantum system that were being investigated.

[section: Quantum Reference Frames]

[sp: Knight]
32:06 Cool. And I think that takes us into figure one. [image: figure 1] {So here} Daniel was foreshadowing, doing a great job, of the holographic screen. {So} This is a holographic screen, a “fancy B” separating systems A and B with an interaction H_{AB} given by Equation six. And {so} this says that {this} this screen can be realized by an ancillary array of non interacting qubits that are alternately prepared by A and then measured by B. Qubits are depicted as the spheres here
32:44 and there's no requirement that A and B share preparation and measurement bases. So these are quantum reading-
32:53 or-
32:53 Quantum reference frames. So this is like they share the ability to prepare or measure that would be like quantum reference frames. And we're going to get into the quantum reference frames just here in a couple of slides. I think with a pretty good example. Cool. Anything to add or do you want to unpack it with the next couple of slides?

[sp: Friedman]
33:13 Just thinking about this as {like} a quantum holograph is sort of the generalization maybe of thinking about this in the classical information. What if this were the chat between Bleu and I? So we could have different perspectives, different reference frames, different semantics, but if we're not in the same chat room, then we're not in the same chat room.
33:36 That's like the holographic screen or the observable that's getting passed between these two systems, A and B, and they don't have to be two people. It could be like a person and some other system on the other side of the holograph / information channel. And the whole question is what kind of math describes that classical information channel case? And how is that similar or different or compatible or whatever,
34:02 with thinking about it not as an information bit from a standard probability distribution, but like a quantum information bit with a complex statistical distribution.

[sp: Knight]

34:17 So they describe the holographic screen actually, as they say, “The holographic screen, ‘fancy B’ has an obvious interpretation in the language of the free energy principle and active inference. It implements the like blanket that separates from B” So we've seen the Markov blanket before and {you know] mentioned it here, but but I think that they are going to implement this holographic screen as this Markov blanket
34:45 Yeah, perfect, cool.
34:47 Oh, and then the quantum reference frame. Fun! So here they say, “We show in particular that the FEP emerges naturally in any setting in which an agent or particle deploys quantum reference frames, namely physical systems that give observational outcomes and operational semantics to identify and characterize the states of other systems in its environment.” And so this is kind of a cool figure {um} that I pulled down.
35:15 So it's like a man on a train- to the man, the train is moving and to the person on the train, the man is moving. Right?. And so it depends on your perspective. And this is {this is} kind of what a quantum reference frame is getting at here. So this says “Quantum features such as quantum superposition are only defined relative to an observer.
35:39 When we look at the train from the point of view of an observer standing on the platform, the train looks in a quantum superposition of different positions. However, an observer sitting on the train sees the observer on the platform and the ball in a quantum superposition.” So it’s a cool illustration of {just kind of} how things look differently depending where you're standing.

[sp: Friedman]
36:01 {Okay} This is awesome. {I,} I like how you brought in the art and the images are a little subtly different, but then in a way that really makes one think. And the classical case would be what if both of them were moving or still? And then they only got to get a frame update once every 2 seconds or once every 5 seconds.
36:21 So then there'd be like still an uncertainty distribution, but it'd be a classical parametric statistics or information theory, uncertainty about location and that's going to be the big question. How is that variance estimation that we've already been exploring and that type of inference related to quantum information where there's something a little bit bigger and more complex or different than just simply low sampling rate leading to positional uncertainty of a massive train that's not subject to so-called quantum effects.

[sp: Knight]
37:01 Cool. Did you want to {what}- so this is kind of cool. Do you want to unpack this slide here, Daniel?

[section: Free Choice Assumption]

[sp: Friedman]
37:07 I'm just looking forward to what the free choice assumption means in a quantum setting. But we just highlighted what is this all going to say about free choice, this specific slide, but also the broader discussion.

[sp: Knight]
37:20 So I agree too. I think the free choice aspect is cool. Here, the authors say “Provided A and B are separable, assuming that there are no ‘superdeterminist’ *a priori* correlations, Z_A and Z_B” What is the Z? I'm not sure what the Z is. Oh! Choices of Z- so the Z is the choice. The choice of A and the choice of B are uncorrelated.
37:45 “This is the free choice assumption. Free choice is often claimed to be essential to science as a practice; if it characterizes any bounded system. Consistency with quantum theory and special relativity together requires that it must characterize all systems. {so} Free choice of a basis introduces quantum noise that is indistinguishable, observationally, from classical noise.” And noise is going to become important here as we move toward the end of the dot zero.
38:15 So yeah. Anyway, that's cool .

[sp: Friedman]
38:18 Okay..

[sp: Knight]
38:27 Next. So Here, they talk about the Z axis in figure one- I should have pasted Figure 1 in here- they say that the Z axis is a reference frame, Free choice of the axis generalizes the free choice of the reference frame encoding each qubit on {the holographic screen} ‘fancy B.’
38:46 Right? So yeah.

[sp: Friedman]
38:50 And the part and red- looking forward to unpacking “A QRF cannot therefore be fully specified by any finite bit string. It is non-fungible in the terminology of citation 40.” It's the quantum ActInf nft crossover that we all needed. We have it, but we need to explore it and find out what it means.

[sp: Knight]
39:12 Super cool. And they say that they consider A and B to be isolated during the time interval between preparation and measurement steps. And I think that we'll get into that in a little bit more like preparation and measurements as we talk about time and memory encoding. Yeah.

[sp: Friedman]
39:34 And that's what this 9 formalism is roughly describing- something like that.

[sp: Knight]
39:41 Yeah so I think…. Yeah.

[sp: Friedman]
39:43 What is happening with it?

[sp: Knight]

39:45 So it says the idea of a computation is this. So you have bits that at one time step going to bits at another time step, and then you have the Markov blanket of one time step going to another Markov blanket at T plus one and then this is it- Z_A- is that free choice that's in there? Oh, no, it's I_F so, I'm not sure what that one is, but yeah, we can, we can unpack that more.
40:14 {I} I will unpack some of the later math, but this, I think it's just important to establish the quantum reference frame anyway. Yeah.

[sp: Friedman]
40:23 That's good.

[sp: Knight]
40:27 Next up, here we go. See, I'm going to start to unpack something when I, when I start to roll out the variables. Here we go.

[sp: Friedman]
40:36 Okay.

[sp: Knight]
40:37 So "We will be interested in what follows and quantum systems consider to be observers that deploy one or more distinct quantum reference frames to measure particular subsets of the bits encoded on their boundaries/ Markov Blankets."
40:52 And yes, these will "effectively decompose the holographic screen 'fancy B' into three disjoint sectors that we will label E the observed environment, F the unobserved environment, and Y the memory sector, respectively." So yeah, we're going to we're going to break that out.
41:13 Yeah. Attention also so that they really talk about the sectors as a sense, right? Like, so I have like my vision sector, my hearing sector, my taste sector, right? And {so, like} I'm making observations of my environment with all these, like my temperature sensing sector so there's all of these different ways to observe the environment with different sectors.

[sp: Friedman]
41:36 Yeah, It's kind of like saying you win some, you lose some you don't play every game. It's kind of like whatever space we're talking about here, which happens to be this boundary that has all these interesting properties, there's some that are being observed, some that are being unobserved, and a special sector that gives continuity of information in some way through time.

[sp: Knight]
42:03 Yeah, so this is cool here, free choice of a decomposition of holographic screen 'fancy B' into sectors with different quantum reference frame-induced semantics is indicative of agency. {So} I like that, and I'm curious to unpack that maybe a little bit more something for to ask the authors about in the dot one.

[section: Non-trivial systems]

[sp: Friedman]

42:27 Yeah. Or also all nontrivial agents are cognitive systems that engage in Active Inference- what is non-trivial? To who? {like how} Do we escape, or how do we escape this infinite multi-perspective multi scenario universe? Or do we just have a way of working with that?

[sp: Knight]
42:49 I do think that they get into non-trivial here in a little while. But yeah, they say nontrivial agent is a system with internal dynamics that breaks the swap symmetry of its boundary Markov blanket (holographic screen)- they're going to start to use these things interchangeably. So I'm just going to keep saying "holographic screen, fancy B' {but} but I guess if your internal dynamics don't break the swap symmetry {or right}
43:15 like if your internal dynamics are trivial or not relevant or {if you don't} if they don't have an affect on the
43:24 boundary maybe {that's} that becomes trivial.

[sp: Friedman]
43:27 Yeah. Wondering if that's the mere versus adaptive Active Inference boundary that we've discussed, or what this maps to, where does this kick in or not? So we'll explore it though.

[sp: Knight]
43:38 It totally seems like it's definitely the mere versus active inference. That's how I interpreted it as I was reading it. So sounds like that to me.

[sp: Friedman]
43:49 Oh, and okay, now we're going to head into some 17 related information because they're going to turn this discussion from QRFs as reference frames to channel theory, which is going to enable this context switching discussion that's important later. So this is brought up in number 17 and 17.1 is where we have Chris Fields and a great discussion there. So continue Bleu.

[section: Channel Theory of Quantum Reference Frames]

[sp: Knight]
44:19 Cool.
44:20 {Yeah. So.} Channel theory of quantum reference frames. {So} I think we've said channel theory is an application of category theory to Chu spaces and I'm not going to read the paper here, but I'm going to go back to some of the slides that we used from 17 because I think that we kind of unraveled it there in a way that was maybe digestible, more so than reading.
44:45 Equations off of a paper.
44:47 So this is a Chu Space. Daniel, what's a Chu Space? So K is a set, A are objects, X are attributes. A Chu Space, "fancy a" over the set K is the relationship between the objects A and their attributes X.

[sp: Friedman]

45:08 I thought of it just like a computer function, like in Python or any language that's just taking in three kinds of data- the set, the objects and the attributes- so describing a large variety of things. But it's just kind of integrating those three types of data in a principled way and enabling transformations between different representations that might look very different or allow for different implementations, but also commonly use {like} all of this information or even just a subset of the information, because that just throws out information which you can always do.

[sp: Knight]
45:51 I really like the Python example. So like if K is the Python dictionary, A are the keys and X are the values, like you can describe the relationship between the keys and the values with a Chu space- like that is what the Chu space does. So like you could say {you know} your keys are apple, orange, banana, and our values are red, orange, yellow.
46:13 and so then the Chu space is how you describe that relationship.
46:18 Color of fruit. Something like that. Cool.

[sp: Knight]
46:21 Okay. So going into channel theory and how Chu spaces work, how channel theory works. So, it says, “In channel theory, Chu transforms become infomorphisms, which are natural maps between classifiers.” {So} Classifiers link tokens to types that encompass them. Like for a stoplight, a set of tokens would be red, green, and yellow- {so} that is the set of tokens..

[sp: Friedman]
46:51 I think this just builds one level on what you described, which is instead of just the data structure of just saying this is what the function is requesting or this is what is being stored memory, this is like saying we're going to interpret some of these edges and relationships as classifier mappings or infomorphisms like information sharing or statistical dependencies or some other type of informational edge.
47:18 But on that space that we've been discussing.

[sp: Knight]
47:22 Yes.
47:24 {so so} They take it to a diagrammatic level where at the center it's almost looks like a pyramid. So there's C and this this core C is the information channel. This is the infomorphism that allows semantic information- and this, I thought was very cool- that it's very different from Shannon information. It's not just bits. It's like the meaning behind the bits.
47:47 {like you can say you know} You can see the word bank, and are they talking about a river bank, the bank that holds your money or like a bank shot in pool? {llike} There's some underlying, I would dare to say, context that is important {or} not just the {the} letters b-a-n-k in that order. {so} It's not just the tokens in a particular order, but it's {like} the semantic context that allows transmission between classifiers.
48:13 {So} I look at this like a shared memory. {So like} If we look at the classifier for A1 here, which would be stoplight- the tokens are red, green and yellow- classifier A2 would be motorist actions, the tokens would be stop, go forward, or I say proceed slowly but it’s really get out of

the intersection. [laughter] That's what yellow means.
48:34 And then there's other classifier types, could be like pedestrian actions, child's game actions like when you're playing red, like green light. Do you run? Do you stop, like freeze, or do you walk? Right. So there's all these different classifiers that can then map via a core information channel 'C'- shared memory semantic information between those
48:55 classifiers. {Cool, okay.}
48:59 {So} Going on, they build from this pyramid, they invert the Pyramid to form this cone-cocone diagram. {So} They say that
49:17 a commuting finite cone-cocone diagram is made of a cone, which is the upright Pyramid, and the cocone, which is the inverted Pyramid on a finite set of classifiers. It illustrates commutativity. So specifically these operators G12, G23 {Like} you can go all the way out to the set {like} there's a commutativity like a superimposability and commutativity between with a shared infomorphism, if that makes sense.
49:53 It also captures a more subtle duality between processes. It enables object files, tokens and histories to be viewed, not as tokens, but as types that organize, respectively, trajectory components, features and feature-based singular categories {and} and make them mutually consistent collections. So where you have all of those classifiers, they are there.
50:16 consistent across the board.
50:18 So you can use them to map and un-map, right?

[sp: Friedman]
50:22 If I can just give a take on this. So G1-2 is saying that there's a relationship between A1 and A2. It could be like appending by one row or maybe changing one little bit through time or having some ability to translate like a state machine or something like that. Let's just say that there's some relationship. And then there's also these F functions that allow the A's to be part of a shared context, like the pedestrian scene that makes sense.
50:51 And then that is shaped like a cone and then that is kind of like sense-making that semantics is making sense. And then this cocone or the diamond shape is where there's C and D who are both like cognitive sense making frames. And then now they're having a shared holograph A or a shared access. And then {it's} that is a different object with a different geometry.

[sp: Knight]
51:28 Yeah, that would be like I'm looking at the same set of classifiers that you're looking at, and we both see, we both know what they mean. We both know that red means stop and green means go…

[sp: Friedman]
Semantically, exactly.

[sp: Knight]
Right, or red could mean apple {depending on} depending on where you're going with that, right? [laughter]

[sp: Friedman]
51:46 So it could be {it could be} an inside joke.

[sp: Knight]
51:48 Yeah.
51:51 Okay, cool. So there's the cone-cocone. Hopefully that was unpacked with some level of….
51:58 intelligibility. {So} [image: Figure 2] Now we can move into figure two where they attach this cone-cocone diagram to measurement operators. Any set of measurement operators that are used to measure the states on the boundary that defines the relationship between A and B, this H_{AB}
52:26 between system A and system B.

[sp: Friedman]
52:29 We're the scientists we cared about. Our context C, we're system A, we're making measurements from our perspective of a screen, and we're setting the context of interpreting those observations in this situation.

[sp: Knight]
52:44 Totally. I could definitely be standing on the other side of that holographic screen, making my measurements from D, from the inverted, from the upside down Pyramid. But they would be left and right pointing measuring off the same screen
52:56 if I was System B and you were System A in that kind of context.
53:00 Cool.
53:04 Anything else to add?

[sp: Friedman]
53:05 No.

[section: Commutativity]

[sp: Knight]
53:07 Awesome.
53:08 Okay. {So} This is just some more, I think, this slide talking about the cone-cocone diagram. But, {but} something that's to point out that there's the dual construction. That is when it commutes. I think I did say that already. {So} When the infomorphisms on the same classifiers where all the arrows are reversed, when it's reversible, then that's a commuting cone-cocone diagram.
53:34 {So} Non-commutativity is the opposite of that. Right. {So} We're going to talk about non-commutativity as
53:38 we go forward.

[sp: Friedman]
53:40 And here, what's one thing that I think is happening, hopefully, is like we have been

discussing this in the context of two different observers having the same semantics from the same screen C and D. And then they say if C equals D or C' equals D', then you can sort of draw another consistent world and this is sort of like a recognition semantics.
54:04 And then the out cone is like an operational or generative semantics in a different way because it's like generating the observations or something like that. But there's going to be like a duel between the Diamond and the hourglass.

[sp: Knight]
54:21 Nice. Cool. Okay.
54:27 All right, here we go. More of this commutativity. {So so} Here they talk about commutativity as Bayesian coherence. Now, we talked a little bit about quantum coherence earlier, but there's this, they're bringing this notion of Bayesian coherence up. {So} Viewing commutativity and Bayesian coherence as fundamental to the definition of measurement, like if I measure the length of the Salamander and Daniel measures the length of the salamander either we can get the same answer or not.
54:58 {So and} Hence, also to the definition of preparation or action on the environment. So this suggests this Born rule, which is… that's what you blew up, Daniel?

[sp: Friedman]
55:10 I don't know what it is. Let's learn about it.

[sp: Knight]
55:15 Yeah. (Okay. Yeah, that,} That one's
55:19 right.
55:21 Let's learn about that one. Let's {let's} let the authors unpack that one for us.
Yeah. Oh, yeah. That's the Born rule. So, here, blow it up again for me? I'll just blow it up, actually myself
55:33 AAAHHH! Too far.
55:38 {So} They say the probability of obtaining X, the state X, is the sum of observations over states- is that observations of states? I should have defined these/ and the probability of obtaining a measurement- is that a measurement? As an observational outcome is the description for coherently assigning amplitudes to components.
56:03 {So} Anyway, we can let the authors unpack that one for us. I can't do it. [laughter]

[sp: Friedman]
56:07 Yeah.

[section: Repeated Measurements and System Identification]

[sp: Knight]
56:10 All right. Repeated measurements and system identification. So this is section 3, moving on. We develop in Section 3 a generic formal description of how one quantum system identifies another quantum system as a persistent entity, a thing. {so} Here they're going to talk about 'thingness' and measures records and compares it states by deploring, deploying specific

sequences of quantum reference frames.

[sp: Knight]
56:34 {And so, like} How do I know that Daniel is a different thing than me, right? Yeah, that's cool. Sometimes I think we're the same thing because we're doing the same thing at the same
56:43 time. [laughter]

[sp: Friedman]
56:46 Is there a thing? Is there a group thing?

[sp: Knight]
56:48 It’s a group thing. [laughter]
56:49 That consensus.

[sp: Friedman]
56:51 We're having a thing at my house

[section: Memory]

[sp: Knight]
56:55 [laughter] That's it. All right.
56:57 {So} They break this section- {So} these sections get really awesome. {So} “Memory, Time, and Coarse graining. The idea that a system must possess a quasi non-equilibrium, steady state solution to its density dynamics, and hence be restricted to trajectories in its classical configuration space that do not diverge exponentially over time in order to be observable as a ‘thing’, immediately raises the issues of time as a measurable duration and of memory as persistent over measurable time.”

[image: Figure 3]

[sp: Knight]
57:30 {and so that} They show in this figure that, “The agent A can only detect changes in the NESS density and deploy them as bases for inference {if actions} and actions, if A can write time-ordered records to subsequently read from the memory sector Y.” {so} Here the memory center is Y, the environment is E and this G_{IJ}, here I think it's better done in the next one.
57:59 Oh yeah, perfect. With the next screen right here.

[sp: Friedman]
58:02 Yeah

[section: Time]

[sp: Knight]
58:03 Yeah, so G_{IJ} is this a time clock, a timestep

58:06 from
58:08 one memory that's the dynamics of internal time, internal clock,
58:12 that's what it is, of the agent.

[sp: Friedman]
58:19 We talked already about the different parts of the screen and how some are being observed, some are unobserved and then there's the memory sector. And here, {like} the unobserved environment is the biggest set I think? It's like mostly, at least in this image. And so one question is just what does this represent in terms of our computers or our sensory apparatus?
58:46 And how is it related to some of the work that they {like} cited and some related work about attention and Bayesian graphs?

[sp: Knight]
58:57 This is a cool representation also, {like} notice that your observations are different and not overlapping, but
59:05 from your memory.

[sp: Friedman]
59:07 {Like} If you're all memory, the new information isn't coming in. If you're not paying attention to anything, it can't have an effect, {like} that type of thing.

[sp: Knight]
59:17 Right, and so this is an illustration of quantum reference frames required to write a readable memory of an observed environmental state E. So E and Y read the state from E and write it to Y, respectively. And the clock is a time quantum reference frame that defines the time coordinate A. So, at the time step you read the environment and then you write it to memory Y.
59:40 And there's papers.

[sp: Friedman]
59:43 A little perception-action, loop with memory

[sp: Knight]
59:48 Yeah.

[sp: Friedman]
59:49 Okay, Figure 4. [image: Figure 4]

[sp: Knight]
59:50 Yep, we're in a loop, sorry. Cool.
59:53 Awesome. The figure 4.
59:57 It's a memory read-write cycle defining one tick, from I to J, of the environment. {so} Here it's like you read from the environment, measure or read-measure, and then write-prepare. So you prepare for the next time step. All quantum reference frames and the comparison

functions are implemented by the quantum dynamics P_A to which is the big block
1:00:26 arrow.

[sp: Friedman]
1:00:27 So if this were like an EEG headset that was measuring at 100 Hertz, 100 times per second, that would be like 100 classical information reads per second, and then you could do signal processing. I think this is kind of like the time step is the sampling frequency of the experimental apparatus that's defined by this partitioning of the blanket ‘fancy B’/ holograph and then subsectors with these different interpretations of being observed, unobserved, or memory components.

[sp: Knight]
1:01:03 And the others say here, they say, “Formally we think of this P_A as the weighted sum of all possible paths from the {boundaries, boundary, from the} boundary the ‘fancy B’ at one state to the boundary the ‘fancy B’ at the next state.” So that is the internal dynamics are how the holographic screen is shifted from (t) to (t+1).

[sp: Friedman]
1:01:28 And also this is where there's the cone. So the B are like those that line of A's that are all lined up. And then now it's bottlenecking, this is the hourglass, and then going back out.

[sp: Knight]
1:01:39 Yes, yes.
1:01:42 We should superimpose those figures for next time.

[sp: Friedman]
1:01:45 Yep.

[sp: Knight]
1:01:49 Yeah. All right. Then “Memory, time and coarse graining- {so} the internal dynamics that operate on those states to maintain a non-equilibrium steady state density are spatially localized inside of the boundary.” And the boundary represents a Hilbert space where we talked earlier and it's not a physical space time decomposition. {So} The boundary B is all those little spheres. (yeah}.
1:02:19 Still.

[sp: Friedman]
1:02:20 What is memory? We’ll discuss it.

[sp: Knight]
1:02:24 Yeah. And importantly, they say figure four illustrates an important {distinguishing} distinction between classical and quantum representations of dynamics. Classical physics assumes the space time embedding and the quantum does not. Hmm.

[sp: Friedman]
1:02:45 It's interesting.

[sp: Knight]
1:02:47 Yeah. I'm curious about the self-evidencing that they mention here also. We'll have to ask them about that.

[sp: Friedman]
1:02:55 Okay.

[section: Learning and Generative Models]

[sp: Knight]
1:02:57 Okay. Cool.
1:02:58 Learning and generative models. I'll let you take this one away.

[sp: Friedman]
1:03:03 This kind of took us almost briefly out of the quantum, but just to give an example of a simpler thing that this is like an elaboration or a generalization of, a Bayesian approach like Kalman filtering, which is just taking, it's like a dragging an estimate through time as new information comes in and so that's what's happening in a sense here with formalism
1:03:26 27. There's a prior and a posterior, and that's moving forward. So it's kind of like using this dragging filter through time, if that were classical information. And then there's something different happening with quantum and that's that {that} piece that we're going to keep on returning to. But this is like a Bayesian analog, and now the math is being used to describe these quantum systems

[section: Identifying and Measuring Systems]

[sp: Knight]
1:03:59 Yes. Okay. Moving on Section 3.3- Identifying and measuring systems embedded in E. {So} "We have so far considered only observers, A, that measure the states of their observed environments E without decomposing E into systems that have their own specific states... {And} The question of how an observer distinguishes a system from the environment in which S is embedded is central to classical cybernetics."
1:04:26 So I think that that's important. Like, are the other agents, do they matter? Are they just part of the environment? {Like} There's always that question of {of you know, is} is it its own thing, that other person over there? Or it's just my perception of my environment?

[sp: Friedman]
1:04:44 And the second part there, {is like} it's that sort of entity niche differentiation or delineation and then under the rubric of object persistence, the conceptuality of thingness to cognitive and developmental psychology. {So} That's like children with peekaboo, {and so it's

like} what connects the child playing peekaboo to the cybernetic entity differentiating causes and how does quantum, with its observer based relationality, connect those areas?

[sp: Knight]
1:05:22 {So} Here they use a special delineation for an environment that indicates the remainder of E when other systems in the environment are removed, and the question of how an observer distinguishes an external system from its surrounding environment prior to and as a precondition for measuring some state of interest is not something that people traditionally address because it is thermodynamically and computationally difficult, demanding special requirements on the
1:05:52 observers. Cool. All right.

[image: Figure 5]

1:05:59 {So} Figure five shows as a system. I think it just shows us {like} pretty much where we are systems S, {you know} here you have A and B identifying a system requires identifying some proper component R that maintains a constant state or density of time average samples as the pointer state of Pi. Right. So you need a pointer to point to the system or density of time
1:06:29 averaged samples of interest varies. {Oh so like} As this goes to attention. Right. So {what is your} what are you pointing to?

[sp: Friedman]
1:06:37 I'll- another way I, I was kind of seeing this one was {this the} it's like a clock hand, so this could be like a time scenario or it could be quantum with {like} the spin or with the angle in a complex field or something like that. But you can decompose the total system S into the time invariant part, which is like your Python data structure, and that's like saying, 'here's {the} the structure of the variables'.
1:07:01 And then just like the variables themself that are time variant, which is like the clock hands. So there'd be like the body of the clock. That's time invariant. And then there's the parts that are time varying. I don't know how that R and P and S partitioning connects back, but that's what this kind of looks like.

[sp: Knight]
1:07:22 Yeah.
1:07:24 I'm also kind of unsure about the pointer states, but I think it's… the interest varies. {So, yeah, but I think that} which I think that points to attention- like as your interest, as your point of focus shifts, like what are you pointing to? Because like as you look here in one direction, there is a set of variables that are there in that direction, like this wall, that corner, this refrigerator or whatever,
1:07:49 and then as you shift here, your interest or attention is shifting to a new set of variables, but you still know that that other set of variables is there. That goes to the object permanence that we were just talking about before. {So like} I know that refrigerator was my first point of view, but it's not in my second point of view.

1:08:05 but I know that it's still there. That {that} to me kind of is how I think about this,
1:08:09 the pointer.

[sp: Friedman]
1:08:12 Cool

[sp: Knight]
1:08:12 It'll be cool for the authors to unpack this one a
1:08:14 little bit more for us.

[section: Markov Kernels and Markov Blankets]

[sp: Knight]
1:08:18 Oh, okay. We did talk about the Markov kernel versus the Markov blanket. Daniel, you so eloquently explained it to me.

[sp: Friedman]
1:08:26 Just one possibility is the blanket is the set of states that insulate the internal and external, making them conditionally independent. And then the Markov kernel could be like that applied through time. And it's kind of like a REMA model. You could have like a temporal depth of an auto regression and then the temporal depth of the Markov kernel through time would be like what time steps are able to carry forward but let's discuss that with people who know better.

[section: Noncommutativity and Context Switching]

[sp: Knight]
1:09:04 Yes. Cool. Okay, good.
1:09:07 All right. {So} Noncommutativity and context switching. {So} We talked about Noncommutativity- we talked about what commutativity means and so Noncommutativity would be the opposite of that. {So} Here they say, “As emphasized by Bohr… 100 years ago, a finite quantum of action partitions the set of all possible quantum measurement operators into a set of complementary non-commuting pairs, the most well known being position and momentum.”

[sp: Knight]
1:09:37 {So} If you're trying to measure position of a particle, you can't simultaneously
1:09:42 measure the momentum
1:09:43 of the particle
1:09:44 at the same time. So that's noncommutativity. Yes. And so why does context switching matter? They say {an observer um} an observer a capable of switching between non commuting quantum reference frames must, to maintain an operable memory, implement a clock that is invariant under basis rotations on the energy between A and B or the physical interaction between A and B.

[sp: Knight]
1:10:12 If measurements made at clock ticks I and J do not commute, however, the corresponding clock operations will not commute. {um, so} Noncommutativity forces tA, which is time or the time step that it takes to record a memory, to be unidirectional and hence memory records to be encoded irreversibly with an accompanying expenditure of free energy. {So} The internal clock thus defines tA as entropic time.

[sp: Knight]
1:10:41 I thought that was super interesting. So it's not like actual time, but it's like time that you paid entropy for? Like time that entropy was expended for.

[sp: Friedman]
1:10:51 Time on the clock.

[sp: Knight]
1:10:53 {laughter} Time requiring work, right?. Or

[sp: Friedman}
Overtime… overtime. Okay.

[sp: Knight]
1:11:01 Something to.
1:11:02 That end. All right.

[sp: Knight]
1:11:07 Cool. So context switching between non commuting, quantum reference frames like position and momentum while holding the other quantum reference frame constant. So that's the one that's constant is here, the one that's ref in this figure 34 equation. What's this thing? It's a diagram, that's what it is. {So} In this diagram number 34 these different pointer sectors U and V could be like the different noncommuting and then you have overlapping but mutually communicating operators in a canonical {canonical} context switch.

[sp: Knight]
1:11:47 That's like someone could be standing not at the
1:11:52 train platform or on the train and observing both of those.
1:11:56 people, I suppose, different frames.

[sp: Friedman]
1:11:59 A bigger {a bigger} context. They each have their own local coherence but it's interoperable so it's part of a bigger umbrella, which is like the big C at the top.

[sp: Knight]
1:12:09 Cool.

[sp: Friedman]
1:12:10 Okay.

[sp: Knight]
1:12:13 Okay, good. So that's diagram 34. If it fails to commute then the observables are non-codeployable. So that's like position and momentum. Those are non-codeployable observables. So non-commutativity in the diagram 34 has been specified in terms of nonexistence of a consistently definable joint probability distribution of conditionals. So that's like the conditional independence, right? This non-{codeployable} codeployability of observables amounts to the occurrence of intrinsic quantum contextuality in relationship to that diagram.

[sp: Knight]
1:12:54 So this goes really back, it speaks a lot to what Chris talked to us about when we did number 17. So.

[sp: Friedman]
1:13:03 Let's get notes on this stuff.

[sp: Knight]
1:13:06 Yeah, for sure.

[sp: Knight]
1:13:09 So they say in 4.2 below that content switching increases variational free energy by generating prediction errors. And like if you're in one context and you have a prediction and then you move to another context with the same prediction, your outcome is going to be different. So it increases {variable} variational free energy, which makes minimizing variational free energy and complying with the FEP more difficult. So like going from my same generative model from one context to another context to another
1:13:41 context makes it hard but can lead to radically better generative models. So you're always updating. your model becomes more {generalized} generalizable under different contexts.
1:13:53 So yes.

[sp: Knight]
1:13:55 Context switching poses a fundamental challenge to any classical formulation of the FEP and a fundamental explanadum -I've not heard that before- for a quantum formulation. I wonder if this provides {like} some evidence for us having a shared reality. And I've brought that up a couple different
1:14:15 times too here.

[sp: Friedman]
1:14:18 Well, it's the fact thing or expression, which is to be explained or explicated.

[sp: Knight]
1:14:26 Nice

[sp: Friedman]
1:14:27 Okay. Now let's get to the paper. What do you think Bleu?

[section: The FEP for Generic Quantum Systems]

[sp: Knight]
1:14:32 We're finally here. We made it. {laughter} This is the best part. Yeah, the FEP for generic quantum systems. So all that background was to lead you here {to the um} to this place where we are now. So how the FEP emerges in this setting and we're going to look at its asymptotic behavior, considering how it addresses the fundamental problem that's posed by quantum concepts switches. Whew

[sp: Speaker 1]
1:14:59 All right, we're getting that All right. Do you want to take this one?

[sp: Friedman]
1:15:07 We're going to go into more detail so that we can get a lot more into this dot zero. But we've seen the variational free energy in the context of perceptual inference where there's a surprisal and a divergence term that gets bounded. So this is kind of like the snapshot question given the incoming sensory observations, how should I update my generative model?

[sp: Friedman]
1:15:32 It's learning. It's like a perceptual Kalman filter.

[sp: Knight]
1:15:38 Yes.

[sp: Friedman]
1:15:39 It doesn't have action involved.

[sp: Knight]
1:15:43 Nice. They have this formulation of prediction error. And this is actually from Section 3.2. It's a representation of the prediction error of system A or agent A. So this is $Er_E(k)$ So K. Let's go to this platform first. So K is that internal time clock. So agent A’s internal time clock tA it counts it, it ticks it up. So fancy B is a holographic screen.

[sp: Knight]
1:16:16 PB is the dynamics of the interaction partner B and then this M sub E with respect to K is the observable behavior of the holographic stream fancy B localized to the sector E up to time tA equals K so like up to up leading up into this point.

[sp: Friedman]
1:16:38 And E is the observed environment just to connect it to the previous formalism, E is the observed environment.

[sp: Knight]
1:16:44 That is it. So here this $M^A{}_E$ this is the Agent A's generative model of the action of the {under} unknown dynamics, PB, with respect to time, I think, oh yeah, on {the Markov} the Markov boundary, the holographic screen fancy B in sector E, the environment, that we looked at.

[sp: Friedman]
1:17:07 Which is kind of like saying you only need to have a generative model on where you're expecting to find observations. If you're going to measure just the thermometer, you make a generative model with just a thermometer, and that's how you get the cone-cocone, Diamond, hourglass that isn't like with extraneous or redundant or incompatible elements.

[sp: Knight]
1:17:32 So here this equation prediction error, it's like $Er_E(k)$ this is the {agent's} agent A's total reducible uncertainty about agent or system B at time tA equals K. {So, so} This is like the uncertainty about another system within the environment. That's why the system separation that we saw in figure five was important. So if we're going to define a system, we're going to look at how other systems interact on the holographic screen.

1:18:03 And then we're going to think about {what} can we predict what that system is doing or not. Like the environment's not doing anything because it's just sitting there. It's the environment. But that's at any given timeset snapshot. So it is therefore an upper bound on surprisal analogous to $F(\pi)$ that we just looked at earlier that Daniel mentioned, the upper bound on surprisal.
1:18:26 Cool. Okay. Here we go. Getting into how the quantum does the FEP.
1:18:29 All right.

[sp: Knight]
1:18:31 So a generic quantum system, A will act so as to minimize Er_x for each deployable quantum reference frame X. A system A has different deployable quantum reference frames- that's analogous to a sense. I have hearing vision, taste, smell, temperature sensing, etc. many different deployable quantum reference frames and I will minimize my total reducable uncertainty at each timestamp for each quantum reference frame.
1:19:03 Yes. Still there? Cool. Okay.
1:19:09 So a trivial agent can be viewed as executing a trivial quantum reference frame.
1:19:14 as only exercising choice of basis for writing to and reading from the holographic screen, fancy B, as a whole, and so satisfies the FEP trivially. Okay.

[sp: Friedman]
1:19:30 Let's have a little roundtable on what that means. We should do it

[sp: Knight] Yeah.

[sp:Friedman] 4.2.

[sp: Knight]
1:19:40 That's it. Or 40.1.

[sp: Friedman]
1:19:44 And here's equation 40. Nice.

[sp: Knight]
1:19:46 There it is. All right.
1:19:49 {So} The authors say uncertainty and prediction error and hence variation of the energy is generated in the current formalism by system A's in-principle ignorance of both the state of B and the dynamics P of B of its interaction partner B. As the bits A reads from the boundary fancy B are written by PB-this is like the the agent or system B is writing to the boundary-
1:20:20 {So} A's ability to predict the future states of its observable sectors and hence to minimize that Er_x for each quantum reference frame X through equation 40 -which we just looked at and we're going to look at it again- depends on its ability to predict the behavior of PB locally on each observable sector. So I have to be able to predict how Daniel is going to smell how he's going to look.
1:20:45 So, so viability if I'm looking at my other agents in the environments over each what temperature he's going to be, is he going to have cold hands or cold feet or something like that. My ability to minimize my variational free energy over another system in the environment depends on my ability to predict their behavior writing to the environment.
1:21:05 on all of those quantum reference sectors.
1:21:09 Good? Enough? Good Enough? Okay
1:21:11 An animal, for example, must employ its available senses, hence its observable sectors, to predict the nutritional value of
1:21:18 food. Okay. Here we go.
1:21:25 So this is where.
1:21:28 I go and it gets a little fuzzy for me. So I was good up until this point, they say the weak interaction limit that allows seperability between A and B is significant. So HAB which is the physical interaction between A and B and hence the boundary, the holographic screen between A and B, must have significantly lower dimension than the physical location of B, and hence the observable dynamics of B.
1:22:01 If the weak interaction limit is to hold. My brain is melting now, all the way down. So anyway, what do you think? Do you have any thoughts on that Daniel?

[sp: Friedman]
1:22:12 {Um} I'm not sure if it means that the sparse coupling has to be sufficiently

sparse, it has to be a lot lower dimension than the system, otherwise is it's not appropriately bottlenecked. So there's a lower dimensional interface that's like sparse coupling. It's physical interaction in the H frame, and it's the holograph slash Markoff blanket with the fancy B but it's the interaction is with the H, and that's kind of what we'll discuss.
1:22:47 Like are we talking about physical interactions of quantum systems or talking about any mechanistic interaction between any mechanistic system? Or are we talking about statistical edges, statistical interactions like an interaction term between two different systems?

[section: Trivial and Nontrivial Systems]

[sp: Knight]
1:23:05 And so just what I've written down here, kind of paraphrases what they said up there. So the ability for a system to predict the dynamics of System B depends on the dynamic complexity of the interaction between System B, which is PB on the holographic screen. So what is B writing to the holographic screen? Like what is my refrigerator writing to the holographic screen?
1:23:26 I would say that's a trivial system, right? It's like outputting a little bit of heat, it keeps my food a little bit cold, most of the time. So I can, with pretty good reliability, predict the dynamics of my refrigerator. I have less ability to predict the dynamics of Daniel or my children who are like total agents of chaos.
1:23:43 Right? {So but but} I want to minimize my uncertainty. I'm pretty certain about what my refrigerator is doing. I don't know what my kids are doing when I leave the room.
1:23:54 Yeah.
1:23:55 So that {that} kind of made sense to me.

[sp: Friedman]
1:23:57 The Schrodinger's cat to Bleu's children pipeline.

[sp: Knight]
1:24:03 We just got there.
1:24:05 Anything else to add here Daniel?

[sp: Friedman]
1:24:09 No, Let's…

[image: Figure 6]

[sp: Knight]
1:24:12 Moving forward… Okay, so here is a little diagram of what it looks like for me to predict the dynamics of my refrigerator. {So so} This is figure 6A, it says the trivial agent in figure 6A looks like a noise source to A. Say yes, my refrigerator is a source of noise. It just like actually literally makes noise and puts out a little
1:24:34 bit of heat.

[sp: Knight]
1:24:35 So it says emission of Hawking radiation from a black hole provides perhaps the most severe example of such a noise source. While the dimension inside the black hole can be arbitrarily large, the internal dynamics are uncoupled from the classical information encoded on the horizon and hence have no classical computational power.
1:24:54 Yes.
1:24:56 Okay, maybe my refrigerator has more computational power than the black hole. I don't know.

[sp: Friedman]
1:25:04 Okay.

[sp: Knight]
1:25:04 Okay, we'll move on. Here we go forward.
1:25:10 So the more interesting parts of A’s option space for prediction are shown in channel B, C, and D where B is non-trivial. If B is non-trivial, it deploys at least one quantum reference frame X of B. {like so} That's sector X of B acting on sector XB as discussed in section 2.5, B’s sectors must be mutually decoherent. So the action of the dynamics on the sector of B is independent of action elsewhere. It is this independence that makes prediction possible. If XB does not overlap any sector for A, B will appear trivial.
1:25:53 So like if the green cone is totally removed from where the red cone is, it's like it's a trivial thing. Like if my kids aren’t here right now, they're not immediately acting on my environment. So they're trivial, I guess, or….

[sp: Friedman]
1:26:10 This made me think about like if if someone was speaking a language that you didn't understand semantically, not even in the cues and in the metadata, like there's kind of speaking past each other even though you're sharing a screen. But that's like an intentional informational interpretation. And this is in a quantum interpretation about the shared semantic frame ranging from identical to overlapping to disjoint.

[sp: Knight]
1:26:39 So in a disjoint wait I'm trying to think of what else would be there. So like a different language is good, but like what about something like radiation emission right? Like so something's emitting radiation, but I can't perceive that radiation. So like the thing emitting radiation doesn't appear like it's impacting my environment at all. So maybe something like.
1:26:57 that.

[sp: Friedman]
1:26:58 And that would be like maybe unobserved, the part of B, the holograph that's not in the observed or memory sector.

[sp: Knight]
1:27:07 Yeah, like that. Okay cool

1:27:10 So the interesting cases are the ones in which A and B’s observable sectors overlap. In this case, intuitively in which A and B can see each other and hence interact in the ordinary, non-technical sense of that term. In Panel B, Sector XB fully contains XA Yeah. Okay. So let's, let's look at the, at the full figure now. So we saw all the ones from trivial and non-trivial.
1:27:40 Okay. So A is a trivial agent, so they're not putting out any cone. B encodes a sector that contains XA but it’s bigger. So I like to think about this as like a teacher. So we're going to get into like teaching and learning. So this is like a teacher that knows more than the student can pick up. Maybe in that kind of way.
1:28:02 So the bits on XB but outside XA encode non-local hidden variables for A. And then in diagram C, the sectors of XA and XB overlap, the areas of non overlap become noise sources. So here it's like you know, I can understand you when you speak English, but not when you speak Chinese. So like when you're speaking Chinese, is this non-overlapping frame. Anyway.
1:28:30 How do you think of that Daniel?

[sp: Friedman]
1:28:32 This is just speculative, but in the case of B, so we're the observer investigator, A. So in the case of, of frame B, there's so much information like in the linear regression data set by Quantum that there's basically anywhere we look we can totally get all the information. So it looks like there's non-local hidden variables because it's like super determined.
1:28:56 In the case of C, the regression has like an R squared of 0.5 or something or 0.6 and so some of it lines up semantically. But if we of course had the perfect attention or the perfect observation, we would be able to make a better regression- but then I'm just trying to take the linear regression, normal information framework.
1:29:23 And then that's where having people familiar with quantum will be really helpful. And I hope they find this discussion and the upcoming .1 and .2 as like just the introduction of hopefully some bidirectional exchange because this may be something where Active Inference is complementary, isomorphic, incompatible, like let's not lose touch with the active inference thread then also how is this relating to quantum and that's how we're going to get up in that quadrant where they're both are.

#40.1

March 17, 2022

[sp: Friedman]
00:11   All right. Hello and welcome, everyone. It's March. 17th, 2022. We're here in ActInf Lab Livestream number 40.1 discussing "A Free Energy Principle for Generic Quantum Systems." Welcome to the ActInfLab. We're a participatory online lab that is communicating, learning and practicing applied Active Inference. This is a recorded and an archived Livestream, so please provide us with feedback so we can improve our work.

[sp: Friedman]
00:39   All backgrounds and perspectives are welcome here. All QRF [Quantum Reference Frames] and video etiquette for Livestream we'll be (hopefully) following. To learn more about ActInfLab, head over to activeinference.org. And for the rest of ActInf Stream 40.1 -- Bleu, thanks for being the facilitator.

[section: “What can we learn about and discuss in reading the paper, "A free energy principle for generic quantum systems?” (https://arxiv.org/abs/2112.15242)]

[sp: Knight]
01:01   Sure! -- So, in this stream today, our goal is to learn and discuss this paper, "A Free Energy Principle for Generic Quantum Systems," by Chris Fields, Karl Friston, James Glazebrook, and Michael Levin. And we have both Chris and Karl on the Stream with us today. So we maybe want to just start off briefly with doing some introductions. So my name is Bleu Knight.

[sp: Knight]
01:26   I'm an independent researcher in New Mexico. And I will pass it off to the first author, Chris.

[sp: Fields]
01:34   {Um}, Hi, good morning, and thanks for attending this discussion. {Uh} This is a paper about Active Inference and how to place the Active Inference framework in a quantum information theoretic setting. So, what I thought I should do to introduce it is just give a little bit of the motivation for doing that.

[section: “How to place the Active Inference framework in a quantum information theoretic setting?”]

[sp: Fields]
02:05 {Um} Quantum information theory is an outgrowth of quantum theory that started in the seventies ({or} or even, you can take it back to the sixties, if you wanted to). And, its goal was to consider physical interactions as <i>*information exchange*</i> processes, and to reformulate quantum theory in this way. And so it has a very natural kind of overlap with what {um}, Karl has been doing with the Free Energy Principle in terms {of} of reformulating physics, {uh} essentially <i>*all*</i> of physics, in information- and decision-theoretic terms.

[sp: Fields]
02:51 So {why} why quantum theory? Why go to this theory that's often thought of as a theory only of very tiny objects that are moving very fast? And the reason is that it's **scale free**. {Um}, and <i>conceptually</i>, quantum theory is very simple. And it has one core hypothesis, which is {the pri} the Principle of Unitarity. And the **Principle of Unitarity** is simply the idea that <i>*total information is conserved*.</i> {Um} So quantum theory is based on a conservation law, a proposed conservation law, conservation of information. So what, going to quantum theory really forces us to do, is to take seriously the project that {um} Karl spent a lot of time on in his {uh} "Particular Physics" paper in 2019 -- which is to understand what we <i>mean</i> when we say that "we've observed a system multiple times" -- what we mean when we say we've interacted with "the same object" multiple times. And it forces us to {uh} (or at least it encourages us to) take that question seriously. And it provides a number of tools for talking about that question. And, we'll talk about that as we get into the paper.

[section: “What do we mean when we say we've observed or interacted with the same object multiple times?”]

[sp: Fields]
04:40 But {um} and that's, in a sense, our motivation: it's to take this {um} very nice, quite abstract, {uh} but (in a sense) very <i>fundamental</i> toolkit that's based around the idea of conservation of information, and apply it to this question {of} of Active Inference. So, I'll let {uh} Karl {uh} pick it up from there. [Laughs]

[sp: Friston]
05:16 Right! Well, thank you! It's a great pleasure to be here. I have to say, I was hoping to <i>*learn*</i> more, [laughs] to get more background! So, this is a great opportunity, from my point of view, just to {ehm} hear a conversation, and probably participate, in terms of how this fundamental scale-free, background-free - and, that's what I think {is} is… one of these, {uh} the most attractive {ehm} parsimonious {ehm} benefits of taking a quantum perspective on this - it sort of reminds me of "the Quinean Desert Landscape," a minimal assumption {which} which I'm always drawn to;

[image: "ActInfStream_#040.1_2_Slide-025.rtf"]
[sp: Friston [as Speaker-1-4]]

05:57   and apply this to some fundamental questions which have actually been beautifully listed for us at the top here [Slide 25] about being so crucially {ehm} how things coupled to other things in terms of measurement and observation and inference. So I'm personally delighted and hungry to <i>learn</i> about how simple questions about the nature of things {we ehm} we observe and measure and make inference about can be <i>cast</i> on this fundamental, uh, in this fundamental or <i>from</i> this fundamental perspective of quantum information.

[sp: Knight]
06:40   Very nice! Thank you!
James, thanks for joining us. Would you like to introduce yourself, and maybe say a few words about the paper; or pick it up from there?

[sp: Glazebrook]
06:51   {Oh, ehm} Well, hello! {Ehm} You may call me Jim.

[sp: Knight]
06:58   Thank you.

[sp: Glazebrook]
07:01   {Ehm, ehm} You {wa, you, you} want a potted biography, do you? [Laughs] {Ehm} Anyway {ehm}, I'm a retired academic and emeritus professor of Eastern Illinois University and adjunct associate professor at the University of Illinois at Urbana-Champaign. {Eehm} My background is {um} global analytic {uh} geometry and some related areas. But in the {uh} last 16 or 17 years, I've been {um, uh, ap} applying mathematical techniques to cognitive neuroscience and {um} foundations {of mathem'} of {uh} quantum biology, and more recently, quantum information {uh} as it {uh} relates to the Free <i>Energy</i> Principle.

[sp: Knight]
07:58   Great - thank you. {uh} Stephen, do you want to maybe introduce yourself and give a thought about the paper, something you like or remembered or you were curious about today?

[sp: Sillett]
08:08   Yeah. Thank you. Hi, I'm Stephen Sillett. I'm {a I'm} based in Toronto. {uh} I'm just doing a practice based PhD in to social topographies and {uh} community development. And {um} I have got background many years ago in chemistry.
{uh} And I'm {I'm} really curious about {um} the way that this idea of something that's scale free {uh} also ties to something which seems to be very specific on scale. I.e where something that's highly contextual and highly {uh} <i>bounded</i> by degrees of freedom at certain scale; and then how something could be inferred that's across all sorts of scales. So {tha} that's really something I'm curious about on this particular piece of work.

[section: "How can the scale-free Free Energy and related formalisms connect with something like Quantum, which is highly specific and contextual, in terms of scale and degrees of freedom?"]

[sp: Knight]
08:53   Great - thanks. Daniel, do you have any other {like} particular [things that you want to] address; or…

[sp: Friedman]
09:02   Just looking forward to seeing the {uh} discussion. And anyone who's watching live can ask a question. So I'm curious about how - also, like Steven said, the specificity of a given experiment interfaces with general aspects of the formalism, and {uh} many other things. But we'll go. Go ahead, Bleu.

[sp: Knight]
09:28   Well, do we want to maybe start there? Do you guys want to speak to {that} that {um} scale-deterministic {um} aspect of the quantum FEP?

[sp: Fields]
09:40   Well Bleu, {I} I can say something here. {Um} {Inf, in} Any information theory {uh} will start with some state space - so, some set of degrees of freedom that have some set of values. And in the paper, we restrict ourselves to finite state spaces because we're really interested in systems that only have access to finite energy, and so finite computational resources. So one <i>starts with</i> a state space; and, in a sense, that state space - {um} when viewed from (kind of) the external perspective of the theorist who's defining it - sets the <i>scale of the problem</i>. {uh} Because in defining the state space, you're saying what the values are of the degrees of freedom.

[sp: Fields]
10:40   And, when you say what <i>are</i> the possible values, you are implicitly making some assumptions about resolution, (so…) {uh} and making some assumptions about measurement. So, for example, if we think of a canonical quantum system, which is a qubit, (just one…) a particle with a spin, {uh} and we say, "the spin can be up or down" - {um} then we've made an assumption about {how} how we can measure the spin. And the most natural mathematical framework is a three dimensional <i>ball of values</i> or sphere of values if you normalize them- {uh} and that's making an assumption that we can measure the spin in any one of three directions.

[sp: Fields]
11:38   {um} And so here we have <i>imposed</i> some possible values {on this} on this set of degrees of freedom. And so, in a sense, we've set a <i>scale</i> for the problem. {um} Similarly, if we're talking about {uh} interactions between human beings, {hah, uh} clearly there are lots and lots of degrees of freedom that we can think of. But we typically think about only a tiny handful of degrees of freedom that have to do, for example, with verbal communication or visual communication, olfactory communication, or some other kind of communication.

[sp: Fields]

12:20   And we always impose resolution restrictions. We can say, "this difference is detectable, and these other differences aren't detectable." And, whenever we make a <i>decision</i> like that, we're setting a scale. And when we characterize the information theory as "scale free," we're just saying that the <i>formalism</i> doesn't change when the scale changes. {uh}So the formalism, the mathematical description, {uh} remains exactly the same, regardless of what scales we pick by choosing the possible <i>values</i> of the degrees of freedom that we're talking about. We don't change anything else about the way the theory works. So {that's} that's all that "scale-free" means. It doesn't mean that we've somehow abolished the notion of scale: {uh} that's part of our experience! {uh} So it's not something we're going to make go away. It's that we haven't changed the way the <i>math</i> works, <i>depending</i> on the notion of scale.

And, you know, {the most} the most <i>notorious</i> example of that {uh} thing that we're <i>not</i> doing, is the historical division of the world into kind of a quantum domain, a classical domain, and a cosmological domain - where you use three entirely different theories, like quantum theory, classical physics, and general relativity, to talk about what's going on. So that's <i>not scale-free</i>. <i>There</i> you're {you're} <i>radically altering</i> the mathematical description to deal with different kinds of problems. So that's what we're <i>not</i> doing.

[We're] trying to use the same mathematical description to deal with all problems.

[section: “ Why do Physicists studying the different scales (Quantum, Classical, Relativistic) employ fundamentally different theories and mathematical descriptions and, can we find a way not to radically alter the application of mathematical concepts, in spanning these across scales?”]

[sp: Knight]
14:24   I think that's a <i>really</i> helpful description, Chris, because so many times when we think about quantum, we think about the very, very, very small, like subatomic particles. And so it's pretty amazing to see math that's interchangeable with my level of existence, like not just tiny little pieces of me, {um} being used from {from} quantum theory. {What um} Is there any other math that you know of, or any other {um} examples of math that's been interchangeable with {like} classical and cosmology and quantum scales, ever before? Or, is this maybe the first time that's ever been done?

[sp: Fields]
15:04   Oh, well, <i>no</i>. {if you look} If you look back to {uh} classical physics in the era of Newton… or {uh} even, I think, the better representative {is} is classical physics as reformulated by Laplace - {um} In that era, electromagnetism wasn't really understood yet. So people were thinking about classical physics in terms {of} of mechanical interactions and gravity. {uh} But the idea at that point was that forces act instantaneously, and forces {uh} act with one over R-squared dependance.

[sp: Fields]

15:50   That was the only force that was really understood, the force of gravity. {uh} Forces were symmetrical, right? Newton's Second Law, action and reaction. And, <i>this theory</i> was meant to be universal. And, so if you look at the structure of that theory, as various people have pointed out - Nicholas Dyson has written a couple of papers about this - it's a <i>non-local theory</i>!

[sp: Fields]
16:23   And {even} even in Laplace's era {hah}, they realized that there was{ a} a deep issue with this theory, that (you know uh) if a rock rolls downhill on the moon, then that immediately affects the state of everything on Earth. That, in fact, immediately affects the state of everything in the universe! So that starts to look a lot like <i>entanglement</i> {hah} that states are not locally independent.

16:54   {uh} And {that} that's the fundamental thing that Einstein attacked about classical physics in formulating {uh} the theory of relativity, was to <i>insist on</i> non-instantaneous forces, which just means forces transmitted by some carrier, which we call light. {uh} But light is really just a carrier of information. It could have been anything, it could have been neutrinos, or something like that. {uh} So what Einstein <i>did</i> that was most revolutionary was to <i>impose locality on physics</i>. And {um} that… in a sense, <i>divided</i> the world into realms that from a <i>*formal*</i> perspective, not just a practical perspective, could be treated independently. And, so it's no surprise that Einstein hated the idea of entanglement! [chuckles] (right) Because entanglement was <i>undoing</i> precisely what he had done to, in his mind, repair physics {hah}. So, yeah, I mean, classical physics of the time of Laplace was <i>*formally*</i> a scale-free theory.

[sp: Knight]
18:25   That's awesome. Thank you for {uh} the clarification there. So Einstein - Einstein broke physics. [Laughs.] Stephen, did you have a question?

[section: “Is it useful to think more about "things" and "thingness" in looking at the world from the smallest to largest scales, in contrast to cases where we take a "systems" perspective?”]

[sp: Sillett]
18:34   Yeah, {ju} just one question so far, following from that, is - as someone sort of thinking about how this might <i>play out</i> in other <i>ways</i> -- Is it useful to think about <i>*things*</i> all the way up, from the smallest; and <i>*systems*,<i> all the way up - <i>*down*</i> - from the biggest? -- And "classical" as being when they were trying to name things as <i>*systems?*</i>

So, that … ‘cause, often I hear people talking "systems! - systems! - systems!" <i>only</i>; but the use of <i>*things*</i> seems to be important, as well. I'm wondering if we should have more <i>*thingness*</i> in our way of looking at the world?

[sp: Fields]

19:15 {(Uh! - Should I comment on that? Yeah, okay, uh, yeah, uh, this…} I think you're raising, here, a really interesting question. And so, when we talk about <i>*things*</i> {as} (as Karl so beautifully emphasized in {uh} his <i>2019</i> paper) we are <i>implicitly talking about</i> something that has an <i>*identity*</i> and that <i>maintains</i> that identity through time. And that's a <i>deep</i> philosophical assumption that's nearly always implicit.

[sp: Fields]
20:05 I mean, people just don't <i>talk</i> about that assumption very much. And {when we} when we use the word "system," {uh} we're, I think, often trying to speak a lot more <i>loosely</i>. But in fact, our language doesn't let us speak more loosely. If I talk about a <i>system</i>, then implicitly I'm saying "I've got a particular state space." That's what a system <i>*is.*</i>

[sp: Fields]
20:37 And if I talk about a different state space, then I'm talking about a different system. So {uh} let's apply that to something interesting like embryology. {hah, oh,} I pick a set of degrees of freedom that are meant to be the degrees of freedom of the <i>zygote</i>.

[sp: Fields]
21:01 And I then, {you know} a few days <i>later</> have a set of degrees of freedom that are the degrees of freedom of some kind of early stage embryo. But I want to say, “this is the same thing as the <i>zygote</i>.” Well, I'm now <i>really abusing</i> my notation, right? {hah} in a really <i>serious</i> way - by… saying that these two are the same thing, even though they have different states. {basis}

[sp: Fields]
21:34 So {uh, this is a} I think this is a <i>fundamental question</i> for any science that bases itself on the notion of a state space: how to talk about {uh} moving <i>between</i> different degrees of freedom and associating those things {with} with some kind of evolution {of a} of a kind of <i>"meta” thing</i> that we regard as a single entity.

[sp: Fields]
22:18 And {this is} this is one reason that {uh}, at the beginning of this paper, {we} we assumed that we have some <i>single</i> system that we divide in two. We draw a decompositional boundary. And that decompositional boundary is basically <i>arbitrary</i> or it's <i>completely</i> arbitrary. But when {we're} we're doing something like <i>embryology</i>, we're looking at a decompositional boundary between the thing we're interested in - the embryo - and the rest of the universe, including us, that's getting bigger and bigger and bigger {ha!}. And so {we need it…} we need a way to talk about that sort of thing. And {we just} we elide that problem in this paper. {we} We talk about a fixed decomposition, {uh that} that divides the entire universe into two parts that we can characterize the interaction between. {But you} But yes, underlying <i>all of this</i> is this much larger question of how we think about decompositional boundaries that are expanding, with respect to some parameter that we call "time." And of course, that "time" is not <i>anyone's</i> observable time, [chuckles] because {we're} we're

trying to talk about it {th} at the level of the universe as a whole.

[section: “Where and how do we think about, select and denote boundaries along which we decompose our study of nature into systems (state space) and environment "identities", in some interaction.”]

[sp: Fields]
23:54 So we very quickly get into extremely deep questions.

[sp: Knight]
24:03 So two things that {um}came up there: {Really for me is like,} Okay, you're thinking about the embryo. Suddenly, that's like a system that's separate from the world. But even {like} within the embryo, {like} where do you draw the line between the placenta and the embryo, and <i>when</i>? So {so} like there's even some fuzzy blurring at the developmental scale. And also really the notion {of} of time, and time irreversibility, and memory, and encoding was just something I found <i>absolutely fascinating</i> about <i>this</i> paper.

[sp: Knight]
24:35 So {so} you mentioned that {um} the quantum, the Free Energy Principle for Generic Quantum Systems, does <i>not</i> imply (like) a spacetime background; (like) it doesn't need a spacetime background to operate. But then {like} <i>brought time back in</i>, in terms of memory and encoding. {um} And I just wonder {if} if anybody maybe wants to {uh} speak a little bit more about that {or} or help us understand how and why you don't need space or time for it to work.

[sp: Glazebrook?]
25:05 Hmm.

[sp: Fields]
25:15 Well, I could talk about that a little bit, {if} if no one else wants to pick it up. [Laughs] {uh} Let me go back to the first thing you said, though, Bleu, which was about boundaries and how hard it is, for example, {to} to draw boundaries in something like embryology. {uh} There's another deep, deep assumption that we <i>make</i>, that the boundaries that we draw in the world are somehow ontological (ha, right) objective and observer independent. And {uh} quantum theory and many other (sort of) theoretical approaches remind us constantly that that's a <i>bad</i> assumption - That {um} drawing, thinking of these boundaries, this **ontic** causes all kinds of formal problems.

[sp: Fields]
26:04 So, for example, the associativity of the state-space multiplication operator becomes invalid. So {you can} you have to throw out the whole vector space formalism. So, I mean, real problems! {uh, so.} So boundaries are observer dependent in any formalism like this. So what do we <i>mean by this</i> "universal time?" It's a construct. It's {it's} a theoretical <i>convenience</i>.

[sp: Fields]
26:40 And we map it onto our <i>*observable*</i> time, which is time measured by <i>our clock</i>. And since {we're} we're the theorists, we can say, “okay, we're going to privilege <i>our clock</i>”, and {uh} we're going to <i>assume</i> that our clock is somehow universal, even though we know that that doesn't make any sense.

[sp: Fields]
27:13 {um} And, when we think of spacetime, {uh} the term "background free" comes from cosmology or quantum cosmology. And it's the idea that, if we want to understand <i>gravity</i> or if we want to understand spacetime as an emergent phenomenon, then we need a theoretical approach that doesn't build spacetime into it. But if we think of <i>biology</i> {hah}: {Uh} how many organisms - what fraction of organisms - have anything like our experience of space? To what extent is space part of the world of organisms that we're interested in?

[section: “To what extent are space and time, as we conceive of them, constructs of our ability to make certain kinds of measurements?”]

[sp: Fields]
28:05 And {uh} to what extent is space as we see {uh} it a construct of our ability to make certain kinds of measurements? And then it's in a strict quantum theoretic formalism, time is not an observable, but <i>distance is</i>. So it's an observable like any other. So {in a} in a very strict sense, quantum theory is not a mechanical theory because it's not really about things going on in an independent spacetime.

[sp: Knight]
28:51 Stephen? Do you have a question?

[sp: Sillett]
28:54 Yeah, I'd just like to comment on… and eh, say thanks for referencing "state spaces" for "systems." I think that's really <i>helpful</i>. Because {uh} I've been wrestling with this <i>dynamical</i> part of systems, which is really <i>helpful</i> to think in dynamics. But most or, a lot of people, when they talk about "systems," they just think about relationships between things and system dynamics. I.e. It just <i>flows</i>, as if it's like <i>things</i> being passed around, rather than dynamical (like) processes.

[sp: Sillett]
29:25 So I think it's helpful to think about state space in that <i>way</i>, to frame "systems." And {I'm, I'm just um, yeah} I'm curious about how we have to be careful about people who use "systems" in those other ways, and don't <i>have</i> a dynamical concept of something which is nonlinear being taken into account. Because that {it} seems to be something that this approach really gives the ability to do. So, I wonder what your thoughts are on that.

[sp: Fields]

30:06   Karl, would you like to say something to that?

[sp: Friston]
30:13   Yeah. I'm not sure it's going to be deeply informed. {So I'm… I} As I'm listening, I'm sort-of trying to translate all these beautiful ideas into a classical framework that I'm much more comfortable with. So the last point is, on the classical perspective, absolutely fundamental. I mean, you start with a Langevin or a random dynamical system that is just cast in terms of flow operators or movement operators that you can cathex with time if you want to. But just to reinforce Chris's point, you know, time and space are both constructs and they're just explanations for what? Well, for these flow operators. So if those flow operators have a dynamics, then implicitly you've got a rate of change with respect to something, which is time. But that's quite a big move.

[sp: Friston]
31:06   So putting things in terms of mappings, I think, is absolutely fundamental. So Stephen, if your point was, that when you need to think about systemic processes or systems from the point of view of mappings, usually associated [with] some <i>time,</i> I get the impression from working with Chris and Jim that, you know, {with the} there is an ordinal or a sequential aspect.

31:36   So just going back to the question, "Where did <i>memory</i> get into the game?" - {that there has to be} there has to be… there can still be sequences or, you know, sets of <i>things</i> that have - constitute - a memory, but it doesn't have to have the attribute {of} of <i>time</i> in the sense that we would understand a flow from the point of view of a differential equation.

32:01   So {I'd like to have the} I'd like to hear {sort of} Chris and Jim's comments on that.

[sp: Friston]
32:08   While I'm talking, though - Just this importance of time as a construct. It does strike me that {you know,} that {takes…} does a lot of heavy lifting, if we just abandon the notion of some universal or clock time, in relation to what I would, from a classical perspective, read the scale-free aspect of.

32:36   And I'm thinking here of the renormalization group. So {um} I'd be interested to know {that you know} (and I'm sure there is) - if there is a renormalization group over the operators of the renormalization group in quantum physics. But from my perspective, {um} {that} that notion of having a scale-free approach is <i>*exactly*</i> {um} what is the aspiration of any {um} (in particular the Free Energy Principle) approach {um} would have, when trying to account for the progressive {um} increase in the scale of a system - but preserving exactly the same dynamics, the same Lagrangians, {the same sort of} (again, from a classical perspective), {the same um} the same {um} **functional forms** for {the} the things that are concerned.

33:30   So - This is to reiterate Chris's fundamental point earlier on, that we're not talking about a commitment to a particular scale, be it very, very small, or very, very big. What we're talking about is a commitment to the same functional forms and the apparatus and the mathematics that underwrite {the} the dynamics, if you like, {and that} at any given scale.

33:53 And then that calls that into question, How do you get from one scale to the other? And I would add one thing that sort of jumps out to you, {when you} when you look at {the} the renormalization group in relation to summarizing dynamics of random differential systems, is that you get this time dilation, or this… you move from one night scale to another time scale.

[section: "What are we talking about when we talk about time and renormalization of the mathematical physics across timescales and how do these relate to on another?"]
34:25 So {I'm} I'm coming back to the point that, you know, when you talk about time, {what scale,} what scale, what "time," are you talking about? Are you talking about evolutionary time? Are you talking about {sort of, you know} the time that the fetus is enjoying in its mother's womb? Are you talking about the timescale appropriate for {the} the fluxes of ions over your cell membrane?

34:52 So the deeper question here is that, "How does one time relate to another?" The people that <i>I know</i> who are interested in this issue, from the point of view of the perception of time or time as a construct, usually fall back on information rates. They usually fall back on {the} the rate of belief updating, or the amount to which you have moved in some belief space (technically, [in some] statistical manifold, if you want, from a classical point of view). But as soon as you say "rate," [you say,] "With respect to what?" And then [it calls you] back [laughs] with "some <i>time</i>" - [but] <i>which</i> time?

35:33 And {where you end up} where you end up is, "Well, okay. I can't talk about any absolute information rate. But I can certainly talk about the number of moves I make at one scale <i>per</i> number of moves I make at another scale. Even, we could be doing that in our heads. You know, when we… very high scales, say from the point of view of a generative model in our heads, dealing with things that unfold very slowly in relation to fast move updating much closer (say) to our sensory organs or actuators. {um} But it does make sense to actually talk about "How much have I moved, how far have I moved, in terms of an information length that's in my belief updating in… {um} at a higher level of a hierarchy or (you know) a higher scale in relation {to the} to the number of moves or how far I have moved. So…

[sp: Unknown]
36:40 [Distracting noises.]
… rapidly. Now, that's putting this over…

36:52 We got somebody chatting away, but not…
All good.

36:55 … do you want to mute if your background noise, please? Over.
Continue.

[sp: Knight]
37:10 Karl, please continue.

[sp: Friston]
37:11 {My… that} That little response was very rambling, because there are so many {just like} questions come up over the past 10, 20 minutes. I ought to pass that to Chris and Jim now, just to get their take on how comfortable they would be by taking the notions of (say) the renormalization group as applied to path-integral formulations in random dynamical systems, and whether that has any **homolog** or any currency in a truly background-free quantum formulation.

[sp: Glazebrook]
37:55 {Well, I don't know…}

38:04 Well, basically I think what Karl is proposing concerning the renormalization group and the van der Waals theories [is] something to be investigated. But {I mean} I'm in consonance with Karl, concerning the aspect of memory from the informational point of view. And - May I speak about the specifics of our construction, namely the cone-cocone diagram, which is a distributed…

38:49 [Interruption.]

[sp: Friedman]
{Yeah, I'll be there.}

[sp: Friecman]
38:50 {Hello? Yep.}

[sp: Friedman]
38:53 {Continue. Jim, I.}

[sp: Knight]
38:56 {Think if.}

[sp: Friedman]
38:58 {You could mute or just.}

[sp: Knight]
39:01 {Right. Yes.}

[sp: Friedman]
39:04 That's all good.

[sp: Friedman]

39:07   We're going to be looking at the cone-cocone. Maybe just Chris or Karl, you can give a first pass. Like, what is this being shown? And also, how does it relate to Active Inference?

[sp: Glazebrook]
39:23   Hello. Okay.

[sp: Friedman]
39:25   [Jim,] Welcome back. Continue with the question.

[sp: Glazebrook]
39:28   uh, local distraction. Um.

[sp: Glazebrook]
39:35   Yes.

NOTE

[section: "What do diagrams of cones and co-cones describe and what do they have to do with Active Inference?"]
[sp: Glazebrook]
39:36   {Okay. Well} {uh} You see, at the beginning of the paper when we {discuss} discuss the holographic screen which underlies the Markov blanket, you have {uh} these preparation/measurement operations which feed into the diagram, Diagram 14, of which the lower part emanating from D-prime is {um} a memory-write system. So as {the um,} the top part is picking up information from the measurement and preparation operators, {um} there is a memory-write system being implemented from the opposite direction.

40:36   {Um} One thing I would like to say about the individual classifiers that we haven't {sort of} fully mentioned in the paper: that an individual classifier can be the result of an algebraic operation {on} on two other classifiers. {Um} These algebraic operations can be of the type such as {uh,} concurrency, {um,} or **orthocurrent**. For example, when you have a system of trains going through a system of stations, {um the} the classifiers in question {uh} can be {um} combined to that extent, and also by choice.

41:32   So {I} I think the scope for what is happening informationally in Diagram 14 is quite significant. {Um} Originally, Chu spaces were applied to such areas {as, as} as concurrency and high dimensional automata. {Um} And also we can look at the possible, or possibilistic, {uh} case. And there are ways of interpreting Diagram 14 in terms of the graph network, too.

42:19   So I know this doesn't exactly answer Karl's questions. But I want to say that there is the mechanism there for the memory write. So - and this is, of course, influential when you see that Active Inference leads to minimizing the variational Free Energy Principle. If you have any questions about those diagrams, please ask me. Perhaps Chris can elaborate on what I'm saying.

[section: "When using the novel strategy for decomposing the mathematical physics, as conceived by the authors and elucidated in the paper, why is any 'Classical' information (as opposed to quantum information) only found along the boundary separating the universe from the system under study?"]
[sp: Fields]
43:07 {Uh} Yeah, let me make a background comment here -- {Uh} Which in a sense goes to one reason that we're using this quantum theoretic formalism. If {we if} we think of everything in terms {of of} of a quantum theoretic formalism instead of a classical formalism, then the only place that there is any classical information in the system is actually on the boundary between the two interacting components. So {um} in that original, {I} (I don't know whether it's Figure One, or…) {or the, the} the very original idea in the paper is that {we} we have some closed system which we can think of as the universe as a whole, or the universe of interest as a whole.

44:16 And it's in some quantum state. And if we divide it into two and we make the assumption that the joint state after the division is separable, that we've divided it in a place where the interaction of the system with itself is weak enough that we can think of the two halves independently, of the two components independently, then we have this natural sense of classical information written on that boundary. And that's the sense of classical information that one encounters in the holographic principle in cosmology.

44:56 And {it's} it's in that sense of classical encoding, that {uh} this boundary serves as a Markov blanket. But since the boundary is the only locus anywhere of classical information, in this formal description, then any classical memory has to be resident on that boundary.

45:24 And {uh} this actually brings to mind a picture which was not included in this paper, [chuckles] but that I'm using in a subsequent paper with Mike Levin, {uh} which really {is} is just thinking of this boundary using a pie chart. And as we pointed out in this paper, {uh} another kind of classical information is the classical free energy flow that powers information processing.

45:59 (So {this} this actually isn't the right picture, but…) {um} And so one can immediately carve off a large chunk of the boundary and say, "Okay, this is just thermodynamic exchange. These bits aren't useful to anybody. {uh they're} They're the bits that are being used, burned as power." (Yeah. This is a better picture for that.) {uh} And then there's a chunk of the pie chart that we can think of as perception, and another chunk of the pie chart that we can think of as action.

46:37 But then some other piece of the pie chart has to be allocated to memory, or there's no internal time, right? Having an internal clock and having a memory are the same concept. If I don't have any memory at all, then I have no awareness of the passing of time and I have no internal clock.

47:01 So when Jim talks about, {uh} in that previous cone-cocone diagram, "a memory-write operation," it's a memory-write operation on the boundary. And of course, {the} the opposite partner in the interaction, {uh} my memory segment of the boundary from <i>my</i> point of view, {uh} might be my partner's perception segment of the boundary, or might overlap with my partner's perception segment of the boundary.

[section: "How do we understand and illustrate "memory" - and related concepts of 'time' in an observer-dependent universe?"]
[image]
47:37   I have no idea how my interaction partner cuts up the boundary from their <i>point</i> of view. {So. Oh, this is} (Yeah, {that,} that's what this picture sort of illustrates.) So this question {of,} of "What is the memory?" also becomes observer independent, {which,} which gets back to this question of time, and the relationship of time to a local clock, and the relationship of a local clock to memory.

48:14   So whenever we talk about time "as observed by someone," {oh,} we're making reference to a local clock; and a memory resource; and, of course, an energy flow that powers that memory resource and prevents it from decaying {Oh} entropically. So {this…} we keep circling back to this abstraction of "the universal time that parameterizes the universal dynamics." But {um} you know, {this} this formalism, like any such formalism, requires that concept as a theoretical construct.

48:57   But at least it doesn't confuse it with {the} the experienced time of any particular observer, which has to be represented in this very different and this very distinct way.

timing
[sp: Knight]
49:14   Awesome! - Thanks! - So I think that is a perfect segue into a question that was asked by Franz Kuchling in the live chat. {um} And also Mike Levin has joined us. I don't know if he's able to talk; he says he is having some Internet issues. Mike, did you want to say hello, before I ask Franz's question, if you can? (You're muted.)

49:42   Okay, I'll ask the question and then we'll see if Mike figures out how to unmute and say hi.
So Franz asks, {"How does the definition of a thing that maintains its identity over time, scales with time, scales or equipment, scale with time scales?"} "How does the definition of a 'thing' that maintains its identity over time scale with time scales?"

50:05   (Well, I still don't get it.) "For example, I would call something a 'thing' if it persisted for some time, with respect to my observational time scale. So in other words, can Quantum theory say something about how to set temporal, observer-limited boundaries of defining a thing?" (There's a lot in there.)

50:27   [Noises off]

[sp: Friedman]
50:30 Could I give one first, Bleu?

[sp: Knight]
50:32 Yeah.

[sp: Friedman]
50:34 We see many ways, {um} some that are actually implicitly scale friendly or scale free, like the hierarchical parametric models in **SPM**, **Statistical Parametric Modeling**, that's separating (like) in a multi-scale experimental design from an experimentalist's perspective, into signal and noise, including the combinatoric interactions in a classical parametric state space. And there's also {um} the {uh} Bayesian identification of parameters, which also is (just as was brought up) scale implies choosing what the state space is.

[sp: Friedman]
51:16 And so: What statistical variance gets partitioned into the noise term or the (kind of) repl term; and what gets partitioned into the wave term, into the signal, into the regression slope rather than the variance term? These kinds of variance-partitioning questions can be approached in a instantaneous sense like descriptive statistics, even if it's about time series. And I think a theme that we're hearing brought up is that, taking repeated measurements seriously brings in a whole host of essentially cognitive features, {like} as well as information theoretic perspective dependance - all of these features that are tucked under the rug or down-projected onto in a special case.

[sp: Friedman]
52:12 If we just assume a synchronous universe or a synchronous regression, it's a totally different scenario. But considering this quantum-statistical background helps us deal with the cognitive modeling and also take the consequences of action into account - because action is implied in the measurement, preparation, recording, experimental Active Inference cycle.

52:43 It was just so subtle in the paper! We said, "All inference in the scheme is Active Inference," but the paper was about quantum in the FEP.

[sp: Knight]
53:01 Thanks.

[sp: Sillett]
53:02 {uh} Could I bounce off what Daniel just said very quickly?

[sp: Knight]
53:01 Sure.

[sp: Sillett]

53:02   Because, I was also thinking about the nature of action. {I thought… I was so} I thought what Daniel just mentioned there ties in with, {is} is: if memory happens via there being some action and then the action defines the memory scale, {there's some… I think that makes… that that} that starts to define a scale.

53:31   So I'm curious that, if there's something different between {the} the temporality of a thing maintaining its "thingnss," and the (sort of) temporality of actions by systems of things. Because I think things can only act to maintain their thingess. But {they then} if they start doing things with others, they become a system. So I suppose you've got {where} where that action still starts to come into the equation.
Or am I mistaken, there?

[sp: Fields]
54:13   Can I address that briefly?

[sp: Knight]
54:15   Yeah.

[sp: Fields]
54:17   Oh, well, I think {a of the} the relevant fable here is {the} the fable of the two drunks who are walking home from the bar, leaning on each other. And if they're lucky, they manage to keep each other upright. If {if if we if} we think of an observer in an environment, and so we draw a boundary between the observer and the environment, and we think about the observer's interaction with its total environment - then we've divided the boundary up (as we were talking about earlier), into a pie chart where {you know} a large fraction of the bits are fuel, and so they're uninformative.

55:20   And there's a perception space and an action space and a memory space and so on.

[section: "What happens when the observer identifies a 'thing' embeddded in the environment and what does it mean to say that the 'thing' retains its identiy over time for that observer?"]
55:27   Now, let's think about what happens when the observer identifies a thing embedded in the environment. So the observer has now segmented or sectored {the} the perception part of the space - into a part that includes bits that represent the state of this thing, and the rest of the perception space, which are bits that represent the background that the thing is embedded in, so, the thing's environment.

56:09   And so the question becomes, what does it mean, to say that "that thing remains retains its thingness, its identity over time for that observer?" Well, that means that that observer is able to maintain this distinction between bits that communicate information about the thing, and bits that communicate information about the thing's environment, So this becomes a cognitive question about the observer.

56:50   So {it's…} the question, "How does a thing maintain its identity?" is replaced in this way by the question, "How does an observer of a thing maintain the thing's identity for himself or for itself? How does the observer {uh} maintain the ability to lock in on this thing as distinct from the environment?"

57:28 And {um} so {let's} let's go to an example, right? Think about **motor babbling** in an infant. So here is this infant. She's lying on her back.
She's waving her arms and her legs around. And what she's doing in this motor babbling is figuring out the relationship between the motor system and the visual system. So among other things, she's figuring out that somehow that something that she sees - some visual stimulus - is actually part of her body. It's a hand And that at a certain moment, she begins to be able to control what this hand is doing, using visual and motor feedback.

[sp: Fields]
58:17 So {here's} here's a living example of an observer {uh} fixing the identity of an object And what we're trying to do here, in a sense, is use this as a… {is} is to insist on thinking about being "being-hood" always in this observer-specific way.

58:45 So I noticed that Karl just raised his hand. So let me turn it over completely to him, to carry on with that or contest it or give a different perspective.

[section: "How do the Free Energy Principle and Markov blankets relate to this observer-dependent individuation and identification of 'things,' in the world? "]
[sp:Friston]
58:56 No, {I don't…} I don't want to contest it. I want to fully endorse that. And if you just look at the Free Energy Principle as classically formulated, it is exactly along the lines of {the} "the thingness" being an attribute of the observer. So if you just start off with the notion of a Markov blanket that stipulatively defines thingness, how is the Markov blanket defined? Well, it's defined by the conditional independence between the dynamics on the inside versus the outside.

59:29 But of course, those dynamics are not observable, once they're on the inside, from the outside - by definition! [Laughs] So you're immediately imputing some magical "observer" that could actually recognize that independence, before you've even defined what a thing is! I just wanted to, {you know} in an abstract and possibly even philosophical way, {um} reinforce this notion that thingness {does…} {you know} is an attribute of something that could possibly observe it, even from the classical perspective of the Free Energy Principle, predicated on the notion of a Markov blanket that is in turn defined in terms of conditional independences or disentanglement.

1:00:16 But that example {of the um} of motor babbling, I think, is, again, a lovely illustration of an observation underwriting thingness - and in this instance, a highly anthropomorphosized thingness, namely selfhood. {You know,} {to} To develop the hypothesis or the explanation for my holographic screen, or all the information on my Markov blanket - that a plausible, parsimonious explanation is that "I am a thing, I am a self, I am me," {is actually… you know,} takes months if not years, to fully, actually, arrive at - as you're an infant slowly discovering that "I am different from Mom," and "perhaps Mom is different from her background," and ultimately "perhaps I am something like Mom!"

1:01:12 So yeah! {These… um} The emergence of thingness, I think, is quintessentially observer dependent, both mathematically and in terms of developmental psychology.

[section: Does the rate of information flow in the modern world affect our rate of belief updating?]
[sp: Knight]
1:01:31 {Thank you.}

[sp: Knight]
1:01:34 {Oh, come [audio unintelligible].}

[sp: Speaker-1-4]
1:01:36 {So let's try to lower my hand.}

[sp: Knight]
1:01:39 {It does that by itself, I think.}

[sp: Speaker-1-4]
1:01:41 {Oh.}

[sp: Knight]
1:01:44 {I love this technology.} So maybe I will put this back to Karl. {Maybe} you were talking earlier before Jim started talking about the rate of information flow and the rate of belief updating. And so I just wonder, I've been curious about this actually, {um, just} in terms of human information. {Like,} are we really bombarded with more information now than we used to be?

[sp: Knight]
1:02:15 {And, um,} is this {like} influencing our rate of cultural change, [of] cultural evolution? Because as a culture{, like,} we update our beliefs more often. Do you think that these two things are proportional: the rate of information flow and the rate of belief updating?

Something I've been thinking about.

[sp: Friston]
1:02:33 Yes. No, I'm sure that's absolutely right. {And, and right,} I think at every scale of analysis. {Um…} So you could look from a point of view of the culture and the availability of information on social media and globalization{, uh,} at a cultural scale. But you could also{, I think, um,} bring us back to motor babbling{, you know}, the degree of belief updating an infant has to do.

[sp: Friston]
1:02:59 {Um,} it's clearly going to be much greater than somebody{, uh,} of my age. {Um… So, you know, time will –} a year in the life of an infant will not be the same as a year in {the life - in} my life {- and um, you know,} and I think that that is a direct reflection of{, of,} the degree of belief updating. Interestingly, that question touches upon the sort of separation of time scales, which I think underwrites everything that we're talking about here.

[subsection: The choice of using a scale-free version of time in the paper and the effect of hierarchical time scales on learning and inference]
[sp: Friston]
1:03:28 {Um,} so, just to stand back again and go back to some of Chris's earlier observations about {the,} the remit of the{, um,} paper in question. {Um,} it was really at any given but not specified scale{, um,} where we could assume{, um,} that, that we didn't have to worry about the separation of time scales from the point of view of a cognitive{, um,} neuroscientist, for example, what we're talking about is inference, where inference in this instance would be read as{, um,} a kind of reading and writing onto this holographic screen.

[sp: Friston]
1:04:07 Or if you want a classical perspective{, um, the, you know,} the updating of{, um,} active and sensory states on the{, on the} Markov blanket{, um,} but under the assumption that{, uh, that, they're} the other things [parameters] that [normally] change at a slower time scale are not changing. And those other things might {not be, um, might} be, for example, at a slower time, {they might} be learning.

[sp: Friston]
1:04:32 So you've got this notion that the formalism at hand, the reading and writing at hand from the quantum information theoretic perspective could be a very good metaphor for inference. {You know,} over a short time period where{, there um, where} things are not changing very quickly from the point of view of the things to be learned. So within a few seconds or minutes of the life of the zygote{, um,} acknowledging that you could apply the same apparatus in the same mechanics at a slower timescale that would account for the transition from a zygote to it to a{, to a} neonate as it learns.

[sp: Friston]
1:05:11 So the difference between inference and learning, I think, is, {is, um} a

nice, commonsensical example of the separation of timescales. So when you ask about{, you know,} cultural information available, {um…} I think you're probably talking about a [time] scale of learning. And {I absolutely, you know,} when we learn, we update our beliefs so that it will be, from a classical perspective, a statistical manifold that {um,} holds those beliefs.

[sp: Friston]
1:05:39 And you're literally moving over that [statistical manifold]. {Um,} and with respect to{, uh…} another [time] scale, {um, then} the degree of belief updating, the degree of asking questions, the degree of read-writing will certainly be{, be} a function of the amount of reading or writing that's going on. And I can imagine that somebody{, uh, somebody} who has access to Wikipedia or uses social media is doing a lot more read-writing than

[sp: Friston]
1:06:10 I was in, say, in the 1960s.

[section: How do the notions of relativism and quantum reference frames come into play in this paper?]
[sp: Friedman]
1:06:20 You moved that [question] to me Bleu?

[sp: Knight]
1:06:23 Yes to you.

[sp: Friedman]
1:06:24 So Karl, you made a fascinating point about connecting the motor babbling and taking it into the informational and the belief updating domain{, um,} into the adults where we're a kind of motor babbling on social media in a way that has different dynamics than before. {Um…}

[sp: Friedman]
1:06:44 And people often give the example of: {like, well,} a year feels longer for a seven year old because it's a seventh of their life. But then for the 80 year old it's an 80th of their life. So that piece of the pie is smaller versus bigger, and that is implicitly the fallacy of the observer independent time, as if there was a linear chart that was being linearly divided by some static observer.

[sp: Friedman]
1:07:06 Whereas another way to look at that or an alternative model is {like} the rate of development or experiences or change or novelty or continuing to explore. {And I'll.}

[sp: Knight]
1:07:18 {mute James.}

[sp: Friedman]

1:07:20 {He’s muted on the left [audio unintelligible].} {Um.} That{, uh,} rate of belief updating could set that internal <i>kairos,</i>, that biological time, {like} that biological information geometry. And so it connects the cognitive sciences and also the statistical perspectives that have been discussed to this time question, which as also brought up earlier, does so much work in so-called dynamical modeling and it just makes me think about how there was a movement from the observer, independent, synchronous into the relativistic, which prepared {in almost like prepared} the{, um,} [Markov blanket] partition to exist so that all these other domains, like the holographic principle, could come into play.

[sp: Friedman]
1:08:14 So my question for any of the authors is where does the QRF come into play and how does this relate to discussion of pluralism and polycentrality?

[sp: Knight]
1:08:31 Awesome question! Jim, do you want to answer?

[sp: Glazebrook]
1:08:41 Well{, um,} I wonder if you can bring up a diagram there in the paper. {Uh, let's see. Sure.} Yes, it's diagram 34 [pg. 29] there. You have a configuration that{, um,} relates the{, um,} QRF to the{, to the} cone-cocone diagrams. {And, uh, we say here that, um…, let’s see, um… well} here we focus on co-deployable observers when this{, uh,} diagram{, uh,} commutes{, uh,} and [it] is interesting, of course, when the diagram doesn’t commute and then you have a kind of intrinsic, {uh,} context{, uh,} plurality. {So, uh, I, uh, I-I-I, think what this is saying is that, um, and} so {th-}there are certain elements of information represented by the logic of the distributed system in question that are{, um, kind of, um,} ambiguous or{, um,} rather {th-}they manifest in classifiers and infomorphisms

[sp: Glazebrook]
1:10:09 that{, um,} aren't {,uh,} defined or{, um,} the code limit that involves “C” at the top there [in diagram 34, pg. 29] {, um,} does not exist. So{, um,} this is a very useful criteria{, um}, I think, to distinguish between {sort of, um, um…} empirical models, which the best part are{, um,} based on deployable variables and what happens{, uh,} when quantum contextuality{, um,} occurs. So that is, diagram 34 [pg. 29] doesn't commute, so {um, th-}there is some sort of discrepancy there {i-}in the{, uh…} mechanism of the quantum reference frame{, um,} relative to the dynamics of the Markov blanket or {th-}the holographic screen underlying it.

[sp: Glazebrook]
1:11:10 So{, um, th-}there is some kind of distortion in meaning{, um…} that results in this sort of intrinsic contextuality. {Uh…}I don't know if that's a satisfactory{, uh,} answer at all, but, {uh,} when this breaks down [audio unintelligible].

[sp: Knight]
1:11:36 {I haven't seen that before. Sounds good.}

[sp: Glazebrook]
1:11:40 {I-I-I-I'm sorry, there’s another local distraction.}

[sp: Friedman]
1:11:42 {It's all good.}

[section: What is a quantum reference frame?]
[sp: Knight]
1:11:44 But Chris, do you want to add onto that or make another comment?

[sp: Fields]
1:11:49 {Oh, }well, I wanted to go back a little bit to the basics of what a quantum reference frame is, because this is a concept that is both very familiar and I think a little bit unfamiliar. {Uhm… }the term was only coined back in the 1990s when {oh, uh th-th-}the idea of{, of,} a quantum measurement was associated with{, with} the idea of{, of} the{, the} units in which the measurement is made.

[sp: Fields]
1:12:34 And {uh,} one of the requirements for{, uh,} a measurement being meaningful - and we're going to get right back to the same issues we've been talking about with respect to time and thingness. {Uh…} But a reference frame is just a way of giving meaning to an outcome. And it's{, it's} what allows outcomes to be compared. So if I have an apparatus like a meter stick, I can go around and measure lengths.

[sp: Fields]
1:13:16 And as long as I believe that my meter stick maintains its identity, as long as I believe that my meter stick remains the same thing, then I can compare the lengths that I've measured. But if I don't believe my meter stick remains the same thing{… oh,} then these length comparisons are meaningless. So the notion of a reference frame is{, is} intimately tied up with this notion of meaning{…} which in this Free Energy Principle context is really a notion of actionability:

[sp: Fields]
1:13:56 {Oh…} can I use what something means to guide my actions in my decision making?

[sp: Fields]
1:14:08 So{, oh, of} this notion of a QRF{, oh,} becomes a notion of{, of giving, of} giving an outcome value that I obtain and write in memory comparably with other outcome values that I maintain and write in memory. And we're very used to, as human beings, we have this incredibly complicated sensory and inferential apparatus that involves many, many degrees of freedom and many, many values that are distinguishable.

[sp: Fields]

1:14:47 So I think if we want to think about something like the role of reference frames and perception, it's{, it's} better to think in terms of something like E. coli. {Oh, and, oh,} so think of a much simpler kind of system that can measure fewer things. Right, E. coli can measure concentrations of salt and sugars of various kinds. And those concentrations are meaningful to it.

[sp: Fields]
1:15:24 {Oh,} those concentrations allow it to make decisions because its internal biochemistry assigns them an actionable meaning. So{, oh,} chemotaxis in E. Coli works{, oh,} because the level of phosphorylation of a particular chemical remains reasonably constant. That the reference frame and concentration levels can be compared to each other as long as that phosphorylation state remains reasonably constant. That reference frame is meaningful.

[sp: Fields]
1:16:07 And so chemotaxis makes sense because E. Coli has, if you will, a slow clock. The phosphorylation state of g_y{, oh,} that assigns, that confers meanings upon its outcomes.

[sp: Fields]
1:16:28 So now we can spool back to what Jim was saying about code deployable reference frames. Reference frames that I can use at the same time, that I can obtain information from simultaneously have to commute. This is what Heisenberg's Uncertainty Principle is about. Oh, and if I can't use them at the same time, it's because they don't commute.

[sp: Fields]
1:16:56 If I use them in different orders, I get different answers. And what that means is that by switching reference frames, I'm effectively changing {the,} the calibration. I'm effectively changing the meaning that I've assigned, and so I think that a very beautiful place to see this, {oh,} is [found in] {the paper,} a paper that we reference here [in "A free energy principle for generic quantum systems"] from Cervantes and Dzhafarov called the Snow Queen Experiment.

[sp: Fields]
1:17:32 {Oh,} the paper is called "The Snow Queen is Evil and Beautiful". {Oh,} it came out a few years ago. And, basically this paper is demonstrating quantum contextuality in human decision making and it's doing it by exploiting differences, context dependent differences in the meanings of words. So {it's, it's,} it's perfectly pointing out this relationship between meaning and co-deployability and its {,its} context dependence in human cognition.

[sp: Fields]
1:18:08 So that's{, that's} a paper I'd very much recommend reading.

[section: The relationship between QRF and information geometry.]
[sp: Knight]
1:18:15 Thank you so much. Karl, did you want to comment on that also?

[sp: Friston]
1:18:19 {Also more, if I may. I'm aware that Stephen also asked a question, but} just to follow up on that {um, uh} beautiful deconstruction. This is more of a question, but I'm going to state it as an observation. {Um,} this notion of{, um,} the QRF as {being} fundamentally getting, {um,} measurements right or metrics right would be understood from the point of view of inference technically{, um,} as getting{, um,} an internally consistent metric{, um,} correct.

[sp: Friston]
1:19:00 And the metric we're talking about is a Fisher information metric. So {i-}if you look at all reading or writing or action and sensation from a classical perspective as just trying to minimize some divergence or some prediction error, what you are saying is that you are trying to find an internally consistent metric in an information space{, um,} that makes sense of your active sampling querying the world.

[sp: Friston]
1:19:34 {Um,} so it just sounded to me that was Chris was saying was about getting {the measure,} a measuring stick, at least behaving consistently. You'll never know whether it's changing its length or at least if it behaves consistently in relation to what you can see of the world. The way that you can query that world actively, then that's good enough. And that of course is{, um,} one way of simply stating the name of the game

[sp: Friston]
1:20:02 in Active Inference [which] is just to minimize your prediction error away. You are now reading a prediction error as a KL-Divergence. And of course the{, the} information that, or the amount, the measurement of movement [from point-to-point on the statistical manifold], the metric is just a path-integral, infinitesimal changes in KL divergence. That is seeing from a mathematical perspective {on the perspective} of information geometries. There's a beautiful link here between aligning your QRFs and getting your generative models right to make the most sense in the sense of minimizing or making it as internally consistent as possible, all your information metrics.

[section: Does the existence of a Markov blanket automatically yield a statistical manifold for the belief state of the agent?]
[sp: Knight]
1:20:49 Awesome, thank you. Before we go to Stephen's question, we have a question or two from Ander Aguirre, in the live chat. He asks, does the existence of a holographic screen/Markov blanket automatically yield a statistical manifold for the belief state of the agent? And is there a “canonical” renormalization procedure for a quantum mechanical system and if there is one

[sp: Knight]
1:21:16 how would the coarse-graining translate into the statistical manifold?

[sp: Fields]

1:21:34 {Oh, I-}I could take one crack at that which is{, oh, if I,} if I'm coarse-graining something. If we think of this in terms of QRFs{, uh,} then I'm deploying a different reference frame with lower resolution. So {the..} in a sense, what's being renormalized is my representation of the units{, um,} that I use to distinguish states of the world.

[sp: Fields]
1:22:17 So if{, if} I have{… uh,} a meter stick{, uh,} that's made of stainless steel that has millimeters indicated on it, then I could go around and make measurements in millimeters.

[sp: Fields]
1:22:38 Then if I coarse-grain to a meter stick that only has half-centimeters indicated on it{, uh,} then I've lost a factor of five at resolution. I've coarse-grained by a factor of five. And so I've{, I've,} in effect, rounded off all my outcome values. And now my function of comparing outcome values is{, is} differently defined{, uh,} because it has to work at this low resolution.

[sp: Fields]
1:23:13 And if I want to{…} compare my previous values to my later values{…} I have to incorporate this explicit round off function into my comparison of values because I've changed my QRF. So{, so…} coarse-graining, {uh, which,} which of course couples to scale changing from the very beginning of our conversation, {uh…} can be thought of as a transition from {oh,} a QRF with some grain size to a QRF for a similar degree of freedom with the different grain size.

[sp: Fields]
1:24:01 {Oh,} and that has ripple effects{, oh,} through everything, including the{, the} free energy cost of memory. {Right,} if I'm writing two bit numbers into memory, then that's a lot less expensive than writing five bit numbers into memory. So{, uh,} this raises {the,} another aspect of this question of renormalization, which is, {uh,} how does it influence, how can I use it{, heh,} to solve the tradeoff problems that arise if I'm an organism with a limited fuel supply – which of course I am{, uh} – going about the world trying to gather, preferentially to gather the information that's going to be most useful to me at the lowest possible cost.

[sp: Fields]
1:25:04 So again, we get back to this key issue{, uh,} in all of Active Inference of balancing{, uh,} the risk of exploration against the reward of new information. And course, coarse-graining is intimate to that and it involves the choice I make of the tools that I'm going to use to make measurements and how that choice impacts my need to allocate computational resources and energy resources to what I'm doing to{… to} the complex task of of getting new information while at the same time surviving.

[section: Can we think of these concepts, like coarse-graining, in the non-quantum domain, for example in terms of SPM and image resolution?]
[sp: Knight]
1:26:01 Awesome, thanks. Then Karl, do you want to speak to that first?

[sp: Friston]
1:26:08 Perhaps Stephen should ask but I can come back to what was just said. Yeah.

[sp: Friedman]
1:26:12 I'll make a note. And then, Karl, it'll be great to have your response to that. And then Stephen, it's your question. So to transpose it into statistical parametric mapping, the true classics. There's a mapping from the measured voxels. which are being{, um,} defined by the resolution of the EEG or the fMRI machine. That's the holograph. That's like what the experimental apparatus is providing, is the measurements.

[sp: Friedman]
1:26:38 Those are the “o” [statistical outcomes/observations/data] in our partially observable Markov decision process. It's the predicted value in the regression. And that space, {you know,} if it's 128 channels in the EEG and they're getting this sampling rate, that is the state space that's being discussed and that's being{, um,} transposed or mapped or connected to a <i>different</i> statistical space with different features. And rather than the voxels there's like the mapping onto resels.

[sp: Friedman]
1:27:07 So, Karl, that's what I would appreciate if this is{, um,} true or not, but those are the resolution elements and that it can be like coarse-graining. And in that stretch meter stick{…} and different space, there's a lot more statistical inference options available that are just not accessible at all from{, um,} the voxel core screening, which is noisier.

[sp: Friedman]
1:27:33 And there's a signal enrichments in the coarse-graining to the resels that's appropriate. And then that gets{, um,} juxtaposed with the contrasts [experimental treatment comparisons] which is the experimental design of the scientist. Like you couldn't differentiate{, um,} A versus B category if you only tested A. So the experimental design, and that's where like the statistics actually comes into play. And then{, um,} just as Chris said, there's the organism with limited food supply.

[sp: Friedman]
1:28:00 And then there's {like} the scientist with limited time, attention, computer storage, processor time, funding, maybe 7 billion people - like it just there's plausibility. And so that's where this operational co-deployment connects with experimental design. And so many of the patterns and analogies exist in the purely classical domain. Of the parametric statistics like SPM in the classical physics {and the flow} and the information flow area that's coming into play.

[sp: Friedman]
1:28:30 And also these more recent [developments] in quantum areas. So Karl would love to hear your thoughts on that.

[sp: Friston]

1:28:41 Yes, of course. {I-I'm mindful of Stephen still has his hand up, but perhaps I'll speak to that and then Stephen can ask a question about it. Yes.} I{-I-I} think{, you know,} these questions and your responses, Daniel, are touching on something really fundamental. So just to{, um,} answer the question from the point of view of Markov Blanket, yes, it does automatically yield a statistical manifold, or at least it looks as if there is a statistical manifold{,

[sp: Friston]
1:29:13 um,} if you can observe the behavior of the thing that you are observing. {Um…} {T-}The second {thing, uh} question which we've been focusing on{, um}, the course-graining, I{-I-I} think that's a really fundamental thing. I would argue that not{, not} to conflate too much the notion of renormalization, which would be, I think, more a question of how you get from one scale to another scale{, uh,} with the notion of coarse-graining{, which is,} which could be read just simply as the degree of quantization or choosing the right resolution element, the right{, uh} coarse-graining on a given QRF at any given scale.

1:35:49 How much of discretization (“carving the world up”) with respect to QRF is ontological or just a reflection of the modern, scientific, perspective of looking at the world?
1:40:10 Final thoughts and wrap-up

[sp: Friston]
1:29:56 You could argue that you could contextualize it but I think there's a more fundamental{, um, um,} argument here{, um,} and that's the argument that there will be, from a statistical perspective, an optimal coarse-graining for any given holographic screen or exchange{, um,} over a Markov blanket. And that's the one that{, um,} statistically maximizes the marginal likelihood{, um,} which you could, if you like, relate to this sort of getting the measurements as internally consistent as possible, maximizing the predictability of the next measurement you make that goes hand in hand with a maximization of the marginal likelihood or minimization of the variational free energy{, um,} that is important to remember, because the marginal likelihood can always be expressed as [model] accuracy minus [model] complexity, where complexity scores the degrees of freedom you’re burning up.

[sp: Friston]
1:30:57 If you remember about {the, t-t-}the bits on the{, on the} holographic screen you do need energy {um, um,} to, from a classical perspective, represent{, um,} what that translates to in a very simple way in terms of probability distributions and functionals is that in maximizing the marginal likelihood or the evidence for your{…} aligned model of the world, you are to maintain a certain degree of accuracy, try to minimize complexity so you're using a few degrees of freedom, you’re coarse-graining to the extent you can get away with while maintaining an accurate account of the{, um,} say, the sensory states or the perceptual states on your holographic screen.

[sp: Friston]
1:31:49 And{, um,} if you know, from the point of view of Active Inference, just think about, well, what would that sort of accuracy and complexity look like in terms of the

consequences of action? You get exactly what Chris was talking about, which was{, uh,} the expected complexity and [audio unintelligible] the risk usually{, um,} and I mean risk in the sense of an economist or Bayesian decision theorist,

[sp: Friston]
1:32:17 it is literally mathematically the same thing{, uh,} the expected accuracy now becomes{, um,} a sort of expected utility,{ uh,} or{, uh} the expected log evidence, the likelihood, the expected likelihood that you would get if you committed to this kind of coarse-graining. So this coarse-graining is absolutely fundamental. It's really interesting to go back to{, um, to, um} all the sources where{, well,} the coarse-graining starts to make a difference.

[sp: Friston]
1:32:51 And I'm thinking here, coming back to Daniel's{, uh,} notion of resolution elements, you know, you find this in Wiener filtering and the matched filtering theorem. There is an optimal level of smoothing or blurring for any given kind of{, uh,} data about which you want to make an inference or you want to assimilate. You see this{, um,} in{, um,} formulations of universal computation, but [they] themselves are based upon Solomonoff induction that get you right back to Kolmogorov complexity and compressibility.

[sp: Friston]
1:33:22 So you see it in{, um,} the drive of that [which] underwrites all formulations of universal computation to maximize compression by minimizing the complexity of your[, of your] message passing [graphical inference algorithm] and getting as efficient and as simple as you can. And of course, the best way to make your account as simple as possible is to coarse-grain it. And I think you also see it{, um,} in the sort of the different levels{, um,} of cognition, in psychology and in neurophysiology, in the sense that the higher level, more efficient{, uh,} ways in which we align our QRFs, or optimize our generative models always lead you to a very coarse-grain constantization of the world.

[sp: Friston]
1:34:14 So, for example, I{, uh,} represent{, I sure,} in my brain on some neural populations, the fact that I am in my study, but I do not represent {not} in terms of very fine grained x, y, z coordinates down to the millimeter, I represented, no, I'm in my study. I carve the world at its joints and those joints basically demarcate {th-}the kind of coarse-graining I bring to the table.

[sp: Friston]
1:34:42 There are all sorts of arguments you can pursue here to{, to} vindicate this. The very existence of receptive fields tiling a sensorium in a way that is covered by discrete quantized receptive fields tells you immediately that the way the brain represents stuff on the inside, {the,} if you can look at it through brain imaging, is in this quantized fashion, this coarse-grained fashion and those that coarse-grainness in the size and the deployment and{, um,} the organization of receptive fields has been optimized at many different temporal scales.

[sp: Friston]
1:35:18 So, you know, I just give you a few takes on coarse-graining of something absolutely fundamental to the structure of a generative model or to the way that {we, um,} we align our QRF to make sense of all of{, of,} the stuff on the holographic screen or at least when when we are, when we are reading from that sense-making, that sense.

[sp: Knight]
1:35:47 Great, thank you! Stephen, did you want to ask a question?

[section: How much of discretization ("carving the world up") with respect to QRF is ontological or just a reflection of the modern, scientific, perspective of looking at the world?]
[sp: Sillett]
1:35:49 Yeah, thanks. This is really cool. There was going to come back a little bit. And now in the past and the idea that you mentioned about the way that we interface or the assumptions of the interface then changes how we{, um,} resolve the thing and the background situatedness of that thing. So{. and so it's like, and so that could then also}, and this is a question in a ways, how can that also{, um}, because if the way that that thing and the assumptions are made sets up, the meaningful inference, the action policy selection and the way things are thought about, how can that itself change the way the brain or the way that organisms look

[sp: Sillett]
1:36:41 {at the,} at what things are. For instance, in the modern world we do see everything as things. We carve things up. We see things as separate like an individual is seperate. Whereas if you go back to sort of indigenous approaches, time for them was cyclical or followed the river going down a hill.

[sp: Sillett]
1:37:01 So there was a{, there was a} complexity focus in a way. It was almost like the mountain car problem of finding the landscape of meaning rather than defining the thing and what it is and carving it. So I'm curious around, is this: how much is the way that the quantum reference field is translated into thinking about what that thing is and how that, you know, compares to, say, our Western cognitive frames, which kind of we measure everything because we can because basically we can control our environment so heavily{, we,} we can make things very accurate.

[sp: Sillett]
1:37:46 Whereas in the past it might have been, you know, the Kalahari Bushmen or the people in the middle of the Amazon, but somehow go with the landscape of complexity so that the way that that is understood is going to be different. So I'm just curious about how you think about that, ways of knowing.

[sp: Knight]
1:38:17 Great question. I wonder also if that ties into the individuality of temporal scales,

like you mentioned{, the,} the cyclical time. And back to Francis' question maybe earlier about how a thing over time that stays a thing over time scales, with the scale of the time or with the cyclical nature of the time, or it reminds me back of{, um, } when we had Chris and Sharma here talking about {like} flattening time.

[sp: Knight]
1:38:52 Maybe that was just Sharma's talk{, but um, yeah.} Anyway, I don't know. Does anybody have any temporal comments?

[sp: Friedman]
1:39:03 Just that there's an analogy to the synchronization of clocks, which is a huge part of computer science and of quantum and other areas. That question of synchronizing clocks seems to have some relationship to cognitive model, not naive{, um,} congruence in terms of synchronization, but in terms of {like} a time zone coordination. So if we're in the same time zone, then there's a comparability but for cognitive states.

[sp: Friedman]
1:39:39 And so I think that will be something awesome to explore in next week's session. And of course in the long run about what that kind of semantic and rhetorical and narrative alignment that isn't congruent but reflects a broader frame which actually the differences within the frame are the search through that field.

[section: Final thoughts, wrap-up, and discussions for .2]
[sp: Knight]
1:40:10 Thanks! Uh, and in the interest{, of,} of temporal comments, I think maybe does everyone just want to go around and give a final thought and maybe an idea of what they would like to see in next week's discussion? And we will start with Stephen.

[sp: Sillett]
1:40:33 Yeah, thanks. {Um, lots of,} lots of interesting things. I suppose I'm curious about this, the way the lapsing{, um,} of the quantum reference frame might scale differently, the assumptions that lead to the collapse could inform different scales of interactions and mixing and blending of behavior and {uh, yeah,} digesting a lot of stuff that's come up. So yeah, thank you for the opportunity to talk to you.

[sp: Knight]
1:41:13 Awesome. Daniel, anything you want to see happen next week?

[sp: Friedman]
1:41:19 We always think of the .0. It's kind of like dropping into the skate park or the bathtub. And so that was like a microcosm of all the threads that get brought together. And then in .1, I feel like we opened up so many areas of possible connection. And so I'll just look forward to the second repeated measurement of this semantic or regime of attention space and see how the continued interaction and engagement updates our generative

[sp: Friedman]
1:41:57 model past the .2 even.

[sp: Knight]
1:42:04 Awesome. Karl or Chris, do you want to give a thought about what you'd like to unpack in the next discussion?

[sp: Friston]
1:42:16 Should I go first while Chris thinks of something very troubling to say? And so from down to a certain extent, Stephen's question as well. I'd like to hear about the principle of unitarity. Entanglement and{, um,} its relationship to this notion of synchronization and the mutual alignment of QRFs between things that are coupled. So coming{, coming, um,} to the regimes of attention, I think that could be a very transparent link there in the sense that contextualizing your QRF, I think for a cognitive neuroscientist would be getting your attentional set right and possibly implicit coarse-graining{, um, um,} that comes along with a particular attentional set. Taking that{, that} notion to attending to others and synchronizing and communicating and living in a universe that is also composed of things like me. Um, brings some fundamental questions about classically generalized synchronization. Quantum theoretically entanglement and enabling that entanglement in the right kind of way{, um,} by aligning your QRFs and getting the coarse-graining right in sympathy with your partner. So that's what I'd like to hear about: the principle of unitarity, entanglement, and how it relates to classical notions of communication, mutual inference and generalized synchrony.

[sp: Knight]
1:43:51 Well, thanks for stealing what I was going to say! I was also going to say how there's one like the final concluding part of the paper. It talks about how the FEP is asymptotically the Principle of Unitarity, and I really would like to dive into that more and maybe any potential implications of that. And now Chris gets the final and cleverest word.

[sp: Fields]
1:44:17 Oh, okay. Just this won't be terribly clever{, uh,} what I was going to do was to recommend a lovely paper by Alexi Greenbaum that we refer to in this paper. {Oh, and oh, oh the,} the closing sentence of that paper is that physics is really about languages. And I think this ties in nicely to some of the issues that Stephen was raising in his last question, which I found very interesting about{, how, you know, how,} how do conceptual schemes evolve at the cultural level and {I, um,} in hearing about the whole issue of reference frame synchronization{, uh,} or reference frame alignment and how that relates to entanglement.

[sp: Fields]
1:45:14 {This,} this really is a question about language and {um… that,} that paper by Alexi Greenbaum I think makes this point very, very beautifully{, uh}, so that that would be a nice thing to look at at some point. {Um… Let's see… this is,} there's probably a newer paper but the one I was referring to{, uh,} is titled something like{, how device free,} "how device

independent methods change the nature of physical theory" or something like that was published in{, uh,} "studies and history and philosophy of science",

[sp: Fields]
1:45:57 {um,} 2017, or something like that. Okay. Anyway, thank you very much for this.

[sp: Friedman]
1:46:04 Yeah, this was{, um,} very interesting and engaging and [we] really appreciated everyone's participation and Bleu's facilitation. So we look forward to seeing anyone just drop in or out when works for you next week at the same time in number 40.2. So till the next measurement.

[sp: Sillett]
1:46:28 Thank you. Take care.

#40.2

March 24, 2022

[sp: Friedman]
00:28   Hello, everyone. This is ActInfLab, livestream number 40.2 on March 24th, 2022. Welcome to the ActInfLab! We're a participatory online lab that is communicating, learning, and practicing applied Active Inference. This is a recorded and archived livestream, so please provide us with feedback so we can improve our work… hear about your QRF. All backgrounds and perspectives are welcomed. We may actually have to change this to: all QRF are welcomed - and, we'll follow video etiquette for livestreams. Check out activeinference.org to learn more about the activities in the lab.

01:13   Today in 40.2, we are continuing to learn and discuss this awesome paper: A Free Energy Principle for Generic Quantum Systems by Fields, Friston, Glazebrook and Levin. {And} We're really appreciative to have several of the authors joining us today. And, in this, “dot-2” [Episode 40.2], we're just going to have introductions and then jump right in to several of the notes that we left for ourselves from last time and see where else it goes.

01:46   {And} Anyone can write a comment in the live chat and we'll just say hello again, pick up with some threads that were left unspooled in the .1 and see where we get in the .2 and how we continue going forward. So, I'm Daniel. I'm a researcher in California and, I will pass it to Dean.

[sp: Tickles]
02:17   Morning, my name's Dean. I'm in Calgary in Canada. My emphasis, I think, is on the practice part of Active Inference and seeing how it gets applied in {in uh} different contexts and situations. I'll pass it to Bleu.

[sp: Knight]
02:33   I am Bleu Knight. I am an independent researcher in New Mexico, and I will [uh} be facilitating the discussion today. But let me pass it off to {oh!} Stephen if he's still here. {Stephen, are you here? {Oh} You're muted, Stephen. We still don't hear you.}

[sp: Friedman]
02:58   Okay. Thanks, Steve. {We will continue on to Dave.}

[sp: Knight]

03:06 {Dave, I don't see..}

[sp: Friedman]
03:07 {Also left. Okay}.

[sp: Knight]
03:08 { Okay. Let’s continue}

[sp: Knight]
03:09 {Let's continue. To the authors we go. So, {uh} let's pass it to Mike first, since you have audio this time.

[sp: Levin]
03:21 Yes, hi!, {Uh, yep}. This is Mike Levin. {Um} I {uh} do biology at Tufts, trying to {uh} understand what {uh, what} living systems are doing at all scales and how {uh} intelligence manifests in various {um} unconventional {uh} embodiments across {uh} them. And they compete in and cooperate across scales to give us the amazing phenomena we see in biology.

[sp: Knight]
03:44 Awesome. Thank you. {Uh} Dave, would you like to say hello? Introduce yourself… Maybe no audio also. Okay. How about, Karl? Would you like to say hello?

[sp: Friston]
04:02 Yes, I would. Hello. I'm Karl. I'm one of the coauthors on the paper. I'm a neuroscientist from London. {Um} I have to confess, I'm a bit of a passenger and admirer of this paper, so I'm here to learn as much {to} as to answer questions. So I'll pass it on to Chris {who’s…}.

[sp: Fields]
04:27 Hi, I'm Chris Fields. I'm also an independent researcher {um} working sort of on the boundaries between physics and biology and information science. {and} I’m sort of convinced that those are all three the same actual discipline [laughs]. So this is a paper that expands on that theme a little bit.

[sp: Knight]
04:52 Great. Thank you. So I think where we left off last time was talking about how the FEP is, asymptotically, the Principle of Unitarity. And maybe, Chris, would you mind leaving this off {um} here? And if you want to point out a specific… maybe<i>*formalism*</i> or place where we should start, I think it was the very last formalism {in the} in the paper, actually. But, maybe, if you would talk us through that, that would be super appreciated.

[section: “What’s the motivation for the idea that FEP is, asymptotically, the Principle of Unitarity?”]
[sp: Fields]
05:29 Okay. Oh, well, {let's} let's talk first informally just about {um} the motivation for this idea

and how it might make sense, intuitively. And, again, I'll go back to {uh} Karl's paper from 2019: the Free Energy Principle for a Particular Physics, which {which} the current paper is obviously modeled after in a certain way. And, as we discussed last time I think, {uh} what Karl was able to show in Particular Physics was that the idea {uh} - the very <i>*intuitive idea*</i> - of a <i>*thing*</i>; of something that exists and {um} importantly {maint..} maintains its <i>*identity*</i> as a single system, over time. And, what that means is that {it's} it can be measured by some other system {um} and, it can be measured <i>repeatedly and reliably</i> {uh} over time, by some other system. So {so} <i>thingness</ii> is associated with repeated measurability.

[sp: Fields]
06:55   And what Karl was able to show and {in} in Particular Physics was that if we assume that something is a <i>thing</i>, then we're effectively assuming that it has a stable, non-equilibrium, steady state density and therefore we're assuming that it has a Markov Blanket, and therefore we can treat it as implementing Active Inference, as {um} constantly <i>predicting</i> its own future existence and behaving so as to make that prediction come true - to the extent that it can. And, {um} such behavior may be prevented or overcomed by its <i>*environment*</i> so the environment of some thing {uh} may cause it to <i>*cease to exist*</i>. (uh}, you know, the thing could be a marble sitting on a table and its environment could include a sledgehammer that's about to come down on top of it, {and} and destroy its <i>*thingness*</i>. {Uh} But, as long as the environment <i>*doesn't*</i> do that {uh, the} the object can continue {to, uh} to execute Active Inference - and maintain its Markov Blanket by so-doing. And of course it's Markov Blanket is what <i>*defines it*</i> as a separate entity - as a <i>*thing*</i> - that's <i>*distinct*</i> from its environment.

[sp: Fields]
08:38   So, let 's translate all of that into QuantumTheory. {oh} In Quantum Theory we have this {uh} notion of interaction as measurement already. And, we have a notion of interaction that is information exchange <i>*already*</i>. So it's very natural to {uh} take this whole picture {and, and} and make the notion of measurement over time precise {in this} using this quantum theoretic formalism. And Quantum Theory also gives us {a} a very natural implementation of a Markov Blanket {uh} which in physics is called a "Holographic Screen". And holographic screens were introduced back in the 1970's to talk about black holes. {um} But a holographic screen is {is} just a reformulation of the concept of a Markov Blanket. {it's} It's a <i>*boundary*</i> that encodes information. And, specifically, it's a boundary between two systems that encodes <i>*all of the information*</i> that one system can have about the other. So {um} it does just what Markov Blanket does; it provides an information encoding boundary that gives the systems on the two sides of it identities for each other by distinguishing them. And this notion of identity in Quantum Theory corresponds to, separability.

[sp: Fields]
10:19   Separability just means, "lack of entanglement". So if the joint… if you have a, two <i>things</i> [laughs] or a <i>thing in its environment</i>, then, if they're <i>not</i> entangled, you can talk about their states independently. If they <i>*are*</i> entangled, then you <i>can't</i>

talk about their states independently. And, so the idea of <i>*thingness*</i> goes away since, <i>*thingness*</i> {uh} implies having some sort of conditionally independent <i>state</i>, right? A NESS density. that can actually be written down. So, all of this fits together rather nicely. And… so if we go back to Particular Physics, {um} the idea of Active Inference, {uh} emerges from that paper as a <i>*fundamental*</i> underlying principle of physics, that {that} tells us what we <i>*mean*</i> *by* “thing” or <i>“system”</i> - that’s identifiable over time. So {this is} this becomes a very <i>*deep principle*</i>, {Uh} deeper than Newton's <i>Laws</i>, because Newton's laws actually talk about <i>*objects*</i> that are identifiable over time.

[sp: Fields]
11:56   And {the the} Free Energy Principle and the idea of Active Inference tells us what we <i>mean</i> when we talk about something being identifiable over time. So {if this is a} if this is a fundamental principle of physics, then one would <i>*expect*</i> [laughs] it would have some relationship to the Principle of Unitarity, which is the most fundamental principle of Quantum Theory. It is {it's} typically axiom one, which one writes down the axioms of Quantum Theory. Oh, {was} was axiom one in von Neumann's formulation back in the thirties {uh} or forties - I can't remember which. So what’s the Principle of Unitarity? The Principle of Unitarity is just the principle that, in a <i>closed system</i>, information is conserved. So, information is <i>neither</i> created nor destroyed in a closed system. So it's a fundamental conservation law, and it's exactly analogous to the Principle of Conservation of Energy by… the… conservation of energy says, “in a closed system, <i>energy</i> is neither created nor destroyed - it 's conserved. So the Principle of Unitarity just says this for <i>information</i> as well as energy. And we know that information and energy are very closely linked {uh, by} by Landauer’s Principle or by {uh} Boltzmann’s {uh} definition of entropy or all of these other connections that make physics <i>informational</i>.

[section: “How does The Principle of Active Inference relate to the Principle of Unitarity?”]
[sp: Fields]
13:38   So, how does The Principle of Active Inference relate to the Principle of Unitarity? What does it <i>say</i> about {uh} of the conservation of information, or what does the conservation of information tell us about {the principle} {of} The principle of Active Inference or the Free Energy Principle? Well, the first thing to note is that, Unitarity applies to <i>closed systems</i>. So {so} <i>thing</i> : (and) environment pairs, {um} and Active Inference characterizes what the <i>thing</i> is doing in response to its environment. And of course, it also characterizes what the <i>environment</i> is doing in response to the <i>thing</i>. {Uh} And another benefit of Quantum Theory is that it makes this symmetry between any system in its environment {ah} <i>manifest</i> – makes it very <i>explicit</i> . {Uh, and} It's already explicit in the Free Energy Principle - I mean, the Markov Blanket has <i>two sides</i> and {Uh, the} the system <i>acting</i> on its environment is the same as the environment <i>sensing the system</i>. And, in the same way that the environment <i>acting on the system</i> is the same as the <i>system sensing its environment</i>.

[sp: Fields]

15:09   So interaction - physical interaction - is information exchange in both frameworks {and} and it's perfectly symmetrical. {Uh} If the <i>system</i> remains identifiable over time, <i>so does its environment</i>. (inaudible) … to exist, its <i>environment</i> ceases to exist because its environment is defined with respect to <i>it</i>. That's why we call it, "<i>its</i> environment" [laughs]. {Uh, so, so all of these} All of these symmetries are built into both frameworks. So {um} the Free Energy Principle is <i>fundamentally</i> about <i>prediction</i>, right? VFE (Variational Free Energy) can be thought of as <i>prediction error</i> or <i>potential</i> prediction error. So the Free Energy Principle is about the <i>system</i> being able to pre… (inaudible, assume <i>predict the</i>) next state of its own Markov Blanket. {Uh} And, if it predicts the next state of its own Markov Blanket <i>perfectly</i>, then VFE is minimized to <i>zero</i> and that's the asymptotic case - <i>perfect prediction</i>. And, there was a question last time about what's asymptotic {in the} in the {qua} claim that the Free Energy Principle is asymptotic with the principle of Unitarity and the asymptotic state, as I think Bleu pointed out last time, is perfect prediction.

[sp: Fields]
16:45   So, {and} now let 's translate all this to Quantum Theory - and this is where the figure in the paper that shows the disk with the various triangles {uh} comes into play. I think that's figure six, but I've actually forgotten. {Uh} Yeah, {it's} it's <i>that one</i>.

[Image: Figure 6. Of the paper showing a disk, labeled **β** (the greek letter beta) in various arrangements with red and green triangles diametrically opposed on the left and right face of the disc, respectively labeled X_A and X_B, illustrating the concept of a Quantum Reference Frame (QRF).]

So, let's now introduce this idea of a QRF, which is just a little package of predictive capability. {Uh} QRF means Quantum Reference Frame. {Uh} As we discussed last time, a reference frame is {um} <i>implemented computation</i> that makes a measurement <i>comparable across time</i>. So, {um} a meter stick, for example, implements a computation of length and it allows us to compare measurements of length across time. {Uh} Because we assume that it's fixed. And of course, we can <i>use</i> a meter stick because each of us has embedded in our brains a representation of <i>length</i>. {Uh} In fact, we have a representation of the 3D coordinate system, {uh} without which meter-sticks would be <i>useless</i>. So we can use external reference frames like meter sticks because we have internal reference frames - like our representation of 3D space - and our intuitive understanding length {uh} that we assume stays fixed over time and that allows our measurements of length to be comparable across time, <i>for us</i>.

[section: "what would it be like for a system to be able to perfectly predict the next state of its Markov Blanket?"]
[sp: Fields]
18:31   So, now let's think about a QRF {uh} as a way {of} of - as something that implements Active Inference or that <i>enables a system</i> to implement Active Inference by allowing it to

compare its measurements over time, right? Prediction is <i>meaningless</i> if you can't compare your measurements over time. {Um} So, and let's ask {what} what would it be like for a system to be able to <i>perfectly predict</i> the next state of its Markov Blanket? Well, the next state of its Markov Blanket is a state that its environment has <i>written</> by <i>acting on it</i>. So {um} our question of perfect prediction is “{wha} what would it be like for a system to be able to <i>perfectly</i> predict the next <i>actions</i> of its environment?” You notice that the system isn't predicting the next <i>state</i> of its environment - it doesn't know the state of its environment. State of its environment is on the other side of the Markov Blanket. What it is trying to predict is the <i>action</i> of its environment on <i>it</i>, which is the only action of its environment that’s relevant. {Uh} And the only action in the environment that’s detectable [laughs]. So {um} its <i>environment</i>, like <i>it</i>, is characterized by QRFs, right? The situation is <i>perfectly</i> symmetrical between the system and its environment {um} so the question of predi… (inaudible)... in its environment. And the system can predict its environment’s actions <i>perfectly</i> only if it and the environment exactly share their QRFs because the QRF not only interprets <i>sensation</i>, it gives <i>meaning</i> to <i>action</i>. So it says: what your action is going to <i>be</i>.   So if I use my meter stick to cut a two-by-four (2” x 4”) , my QRF - the meter stick – is <i>guiding my action</i>. It's giving it <i>meaning</i>. It's making it <i>repeatable</i>, in the same way that it makes my perceptions <i>repeatable</i>. And again, {that's,} that's why we <i>use these things</i> - we want to be able to act in repeatable ways as well as <i>perceive</i> in repeatable ways. And if we <i>can't</i> act in repeatable ways, then again, the notion of prediction becomes <i>meaningless</i>. So {um} perfect prediction corresponds to perfect QRF alignment.

21:15 So the question becomes, well, what is perfect QRF alignment <i>correspond to?</i> {and, oh} Jim Glazebrook and another colleague, Antonino Marcianò, {uh} who's {a physicist} a physicist in Shanghai, showed in a previous paper that {perfect} perfect QRF alignment between a system and its environment is <i>only possible</i> if the system and environment are entangled. So, perfect QRF alignment corresponds <i>actually</i> to the <i>collapse</i> of the Markov Blanket because it corresponds to the <i>collapse of separability</i>, which means that the NESS (non-equilibrium steady state solution) is no longer well defined because it's no longer in a {dep} conditionally independent state and you can <i>see that</i> if you think of what perfect cure of alignment <i>means</i> – it means that your actions correspond <i>exactly</i> to my predictions. A conditional statement - it's an <i>exact</i> state. So if I predict that you're going to do X, then <i>you're going to do X</i>, <i>period</i>. {Oh,} Which means that <i>your state</i> is no longer independent of <i>my state</i>. Your state actually <i>depends</i> on my state and my state correspondingly actually depends on <i>your</i> state. If you predict that I'm going to do X, then I will do X. That's what perfect prediction <i>means</i> {uh} when we translate it into this {uh} QRF based concept. So, perfect prediction and {uh} the <i>collapse</i> of separability are the same thing. So, the <i>asymptotic limit</i> of the FEP, which is perfect prediction, corresponds to the collapse of separability. Well, the collapse of separability is just <i>entanglement</i> [laughs] and, the principle of <i>unitarity</i> is the claim that: “any isolated system left to its own devices {uh} will evolve its state - which is the <i>joint state</i> of any two of its components, will evolve {toward} toward {um} complete entanglement”. It will evolve toward a pure state {in} in quantum theoretic jargon. So it's in this sense that the FEP is asymptotically the principle of unitarity. It's that if its asymptotic condition is the <i>same</i> as the condition that the principle of unitarity imposes on <i>closed systems</i>, i.e. on <i>system, environment combinations</i>, where - whenever I say environment, I {mea} just mean everything that <i>exists</i> that's not the system of interest. So a system, environment combination is always a closed system by definition. So {so} that's my introduction and, {uh} we can start on discussion.

[sp: Knight]
24:56   That's great. Thank you. Stephen, did you have a question?

[section: "What happens at higher-scales, larger than quantum-scale?"]
[sp: Sillett]
25:00   <i>Yes</i>, you can hear me okay? Excellent. I was just going to ask - that's really helpful, {uh} there's a lot in there, obviously. I was going to ask, in terms of the <i>pure unitarity</i> – would that be what happens, say at the electron or the - kind of - these normal quantum-particle <i>scales</i>? And, as you go to scales <i>above that</i>, {you} it becomes more and more approximate - you have less of this {uh} isotropic, you know, {this} this quality of <i>knowing</i> and entanglement.

[sp: Fields]
25:38   Well, that's {that's} a very deep question and it's a very good question. {uh} Let's think about {the, the} the canonical entanglement {experience} experiment, the sort of Bell EPR experiment.

25:52   So {I'll} I'll draw it with my hands here [laughs]. So, in the canonical experiment, you've got a source and it's located here {in the} in the middle of my face. And it produces an entangled pair of something, photons or, electrons or, buckyballs or, whatever you want. And they travel apart at the speed of light or something very close to it.

26:20   And, at some point they encounter two symmetrically placed detectors and the detectors are operated by observers who are always called Alice and Bob. And, {uh} these detectors measure <i>something</i>. And, in the canonical experiment they measure <i>spin</i>. And what Alice and Bob each observe <i>independently</i> is a random distribution of spins. And, if we think of this as a two dimensional experiment, then {uh, they} they either measure spin up or spin down and some coordinate system. So, Alice and Bob, each pick a Z axis that defines up and, with respect to their local Z axis, they see a random distribution of up and down. Now, {um} things get interesting when Alice and Bob <i>later get together and compare their results</i>. And, what they find is that, whenever Alice observes up, Bob observes down and vice versa. And so, they conclude that their results are classically <i>correlated</i>. But then it gets <i>more</i> interesting because, what we allow Alice and Bob to <i>do</i> is, <i>constantly alter</i> the <i>direction</i> that they detect the spin in with respect to their own local<i>Z axis</i>.

28:02   So, you can think of the spin detector as like a polarization filter, S, like a pair of sunglasses. And what Alice and Bob can do is randomly and independently change the tilt of their sunglasses {uh} while they do this experiment. And {in,} in real implementations of this experiment - when it was first implemented (phone rings) {sorry} by {um} Alain Aspect in his lab in Paris in the early 1970s. {Um} and has since been repeated probably <i>hundreds</i> of times by different groups all over the world including the Chinese, using a satellite to generate the entangled pairs and measuring them - {thousands of} a thousand or so kilometers apart.

28:57 {Um} So, if you remember the speed of light ‘s, a foot per nanosecond, so you've got a lot of nanoseconds in there - if you’re a thousand kilometers apart - to play with. And {the} so the <i>trick</i> in this experiment is that Alice and Bob can <i>change</i> the direction of their detector <i>within the time it takes</i> for the entangled pair to get from the <i>source</i> to the detectors.

29:25 So, if it takes ten nanoseconds to get from the source to the detectors, they have to be able to change their detectors within ten nanoseconds. So, that's why you want detectors that are far apart. So, Alice and Bob, re-do the experiment, {changing} randomly changing the directions that they're measuring, {uh} with respect to their local Z axis. And then they get together again to <i>compare their results</i>. And what they <i>find</i> is that {uh}

[sp: Fields]
30:00 if Alice observes <i>up</i>, Bob will observe <i>down</i>, {uh}, even when they've been randomly and independently <i>changing</i> the directions of their detectors. So, {uh} one way to put that is, “if Alice decides to <i>rotate her detector 45 degrees</i>, then Bob's result will <i>automatically</i> be rotated 45 degrees. And, it's symmetrical, {so, vice} - <i>and</i> vice versa.

30:35 So that's <i>not</i> classical correlation, that's classical correlation that's <i>robust against manipulation</i>. So, {oh,} I was discussing this with Karl a while back and, I used this example: {uh} if you and I are {uh, classic} are <i>classically correlated</i>, then we may have the same beliefs about <i>something</i>. So, {uh} we might both believe that the Earth is round. That's classical correlation. {um} Now suppose someone convinces <i>me</i> that the earth is <i>flat</i>.

31:18 {if}, If that happens and <i>you</i> then believe that the earth is flat, <i>that's entanglement</i>. That's classical correlation, that's robust against manipulation. So {it's} it's correlation, <i>no kidding</i>! – {uh,} correlation {that} that <i>survives the environment doing something to you</i>. And, so {uh} now let's go back to this question: “is this {is this} an effect that <i>only occurs in some microscopic domain</i>. And, the answer is; it's an effect that was first described by a theory that was <i>intended</i> to only describe a microscopic domain, right? Quantum Theory was developed to deal with {nuclear and} atomic and nuclear physics.

32:17 And so there’s this idea of the <i>Quantum World</i>, which is very small. But, the <i>math</i>, of course, applies across the board. And, trying to think of Quantum Theor… trying to think of classical physics as a <i>limit</i> - a <i>mathematical</i> limit of Quantum Theory -

always runs into <i>problems</i>. And the problems are always that numbers go to infinity that it shouldn't be infinity.

32:47 So, it's <i>not really accurate</i> to think of classical physics as some sort of mathematical limit like, “Hbar goes to zero” {uh} of <i>Quantum Theory</i>, because if Hbar goes to zero, lots of relevant energies go to <i>infinity</i>. {um} And {this is} this has been known for a long time. Nonetheless, {it's} it's constantly <i>taught</i> in this <i>classical limit kind of framework</i> that isn't really correct.

33:22 {Of the} So, one point of doing Bell-EPR experiments in larger and larger distances is to demonstrate that Quantum Theory is not <i>really</i> a microscopic theory [Laughs].

33:40 {Uh} So, if you think of an entangled state; an entangled state is <i>one object</i>. It's not two electrons that happen to have some mysterious relationship, it's <i>one object</i> that has <i>one state</i>. Remember what entanglement <i>means</i> is, <i>non-separability</i>, <i>non-independence</i> across any decompositional boundary. So, an entangled pair is <i>one thing</i>. And, what the Chinese were able to demonstrate {uh} was you can have <i>one quantum object</i> that's over a thousand kilometers <i>long</i>.

34:20 Now, <i>that's not microscopic</i>. That's <i>big</i>. {Uh}, a nice way to think about entanglement was introduced by Leonard Susskind,{uh} quite a few years ago and, Raphael Bousso {uh} with their idea that {uh} an entangled pair is the same thing as an Einstein Rosen Bridge in spacetime. And, an Einstein Rosen Bridge is a black hole and a white hole connected in the end.

34:50 Or you can think of it that way. It's {it's} a <i>topological connection</i> in spacetime that simply <i>identifies</i> two points in spacetime that would otherwise be considered <i>distinct</i>. So, this emphasizes that {um} if you have an entangled pair, there's no <i>distance</i> inside it. {Uh,} If you have two entangled electrons - for example, they're a thousand kilometers apart - as far as they're concerned, they're right next to each other.

35:22 And in fact, as far as they're concerned, they're located at exactly the same point in spacetime. And, that's what this ER Bridge notion <i>emphasizes</i> to us. {Uh}, there's really no separation here; that the separation is an artifact of <i>our observational capabilities</i>. It's not a characteristic of the entangled state. [Inhale] So, entanglement actually calls into question what the idea of distance even <i>means</i>. {Uh} It makes it - forces it - to be relative to <i>us</i>.

35:54 And that's {that's that's} why there's all this discussion of <i>“emergent spacetime”</i> in quantum <i>gravity</i>, in quantum cosmology. Because if you <i>think about things</i> from a <i>straight Quantum Theory point of view</i>, {uh} spacetime is an <i>observable</i>, it's {it’s} just something {it's, uh, aw, it’s something} that's <i>relative</i> to how observation is made. It's not an intrinsic property of anything. It's not <i>“ontic”</i>, as they say. {Um} So, let's go back to this question again. {um} If we <i>think about entanglement</i> and we think about

<i>observation</i> {uh} and we think about entanglement as something that's <i>observed</i> by <i>comparing observations made by different observers</i>, right? Neither Alice nor Bob in that experiment can detect entanglement.

36:53   {uh} They only realize that there's an entangled state when they talk to each other after they've done the experiment.

37:02   {um} Then, this question of <i>scale</i> becomes a question about <i>how observers interact</i> and what observers can <i>know</i> about <i>each other</i>, and about each other's experimental apparatus. So, when I described {the} the entanglement experiment, I said Alice and Bob each have their <i>own local Z axis</i>. And, when they get together and they discuss their results and they <i>compare their results</i>, then they make a <i>very important assumption</i>, which is the <i>assumption</i> that their <i>Z axes</i> are comparable.

37:47   So, if during the experiment <i>Bob's Z axis</i> was <i>varying at random</i> with respect to <i>Alice's</i> Z axis, then {their results,} comparing their results would be <i>meaningless</i> because they'd be measured with respect to completely different reference frames.

38:09   {Uh} So we have to make this assumption that they have the same <i>Z axis</i>. Now, interestingly enough, <i>that assumption by itself</i> {uh} tells you that <i>Alice and Bob</i> have to be entangled, or their <i>Z axis</i> have to be entangled. So {uh} the idea of entanglement kind of <i>expands</i> to take in <i>all aspects</i> of the experimental situation. As soon as one starts <i>unearthing</i> these <i>assumptions</i> that we <i>make</i> to {um} talk about <i>comparability between experiments</i>.

38:57   So, let's <i>reel the tape back</i> about <i>half an hour</i> [Laughs] and we see {that} that quantum reference frames are what make experiments comparable for {uh} <i>an observer</i>. It's (the) similarity or <i>comparability</i> of quantum reference frames that make comparing experiments possible for <i>two observers</i>. {uh} <i>But</i>, if the two observers exactly share their <i>QRFs</i>, in a way that's robust against environmental manipulation, then they're <i>entangled</i> [Laughs].

39:36   So, we've kind of come {fulls} full circle here. {um} It's {one} one can <i>make</i> this notion of entanglement as <i>macroscopic as one likes</i> and again, this is {um} in a sense, {why} why quantum gravity and quantum cosmology are interesting. {um} It's what drives things like the Blackhole Information Paradox, which you may have read about. {Um so.} So, {so} we're now getting into, in a sense, <i>very fundamental physics</i>.

40:19   How [Laughs]{how} do we {uh} - what's the <i>relationship</i> between entanglement and the <i>concept</i> of spacetime? What's the <i>relationship</i> between Quantum Theory and General Relativity? {uh} which is - you know - the big {the big} <i>question</i> in physics, from one point of view. {uh}, But the <i>short</i> answer is: you can make entanglement as <i>big as you want</i>.

[section: “What are the implications for predicting my own behavior, in relation to entanglement and QRF?”]
[sp: Knight]
40:49 That's great. Thank you. That actually leads into a question that <i>I</i> had back - way back when we were talking about entanglement in Quantum Reference Frames. {um} So, I was just thinking, like, if I cannot <i>perfectly predict my own behavior</i>, is my <i>Quantum Reference Frame</i>, like, incompletely aligned with my own Quantum Reference Frame? Like {uh}, I mean, maybe we’ve all had the {uh} experience of, you know, predicting: “if I kick the ball in <i>this way</i>, I predict it'll go over there” - but, like, it doesn't actually go over there. [Laughs]

41:22 So like, I mean, we predict and we're off. Our prediction {is,} is <i>not accurate</i>. So, is it like actually a <i>temporal separation</i> {that} that {like} <i>makes that happen</i>? Or {or} what do you think happens in those circumstances where my QRF appears unaligned with my own QRF?

[sp: Fields]
41:45 {uh} Now, that's also {that's also} a beautiful <i>deep</i> question, and it points to something that I think {uh} <i>can</i> and <i>should be</i> stated as a <i>general theorem</i>, which is: “{uh} no system can <i>perfectly predict</i> {can perfectly predict} its own <i>state</i>. {uh} No system can <i>observe</i> its own state - its own <i>total</i> state. {uh, so, uh} So, that situation is {um} <i>ubiquitous</i> and <i>unavoidable</i> [Laughs]. And, {uh} one could phrase it by saying {um}: “a <i>system</i> can have {a, a} a QRF or a <i>meta-processor</i> as - one often uses that vocabulary - that represents <i>itself</i>. So, we all have a self-representation {um} that's, in a sense, <i>metacognitive</i>. We claim to know what we believe and things like that. But, of course those beliefs are all {uh} (1) <i>very coarse-grained</i> {uh}; (2) <i>extremely</i> incomplete; {uh} (3) useful for making predictions but they're often <i>wrong</i>. And, you know, {this is, this is uh, this poi} this point has had <i>huge technological consequences</i>.

43:34 I mean, think back to the history of Artificial Intelligence. Right? In the <i>‘70’s</i> {uh} there was {the} - the <i>huge new wave</i> was expert systems and, you know, AI people {de} redefined themselves as knowledge engineers who we're going to go out and <i>interview experts</i> and <i>find out how experts did things</i> and <i>code it up in computers</i> and soon we'd have, you know, artificial expert systems that did anything interesting. And, that <i>whole business failed utterly</i>.

44:11 Alright? It was a <i>complete disaster</i>. It <i>didn't work at all</i>. <i>Why</i>? {we} The simple explanation for “why” is that experts can't <i>tell you</i> what they're <i>doing</i>. Expertise isn't <i>verbalizable</i> [Laughs]. And it's not just expert <i>piano playing</i> isn’t verbalizable - you know, expert <i>systems engineering</i> isn’t verbalizable, expert <i>computer</i> programming isn’t verbalizable. {um}, and {that's} that's just an illustration of the fact that our meta-processors don't <i>actually</i> have a complete model of the <i>rest of us</i> [Laughs], much less a model of the rest of us <i>plus the meta-processor</i>. {uh} So {it all} it all comes <i>back</i> to this <i>general principle</i> that a system can't represent itself, and so it can't predict its own behavior.

[sp: Knight]
45:09 Awesome. So, between <i>this</i> work…

[sp: Fields]
45:14 {ac, ac} Actually, I should ask Karl to <i>comment</i> on that tirade because he's also thought about this in an <i>extraordinary</i> amount.

[sp: Friston]
45:27 Well, I'll certainly make the comment {that uh that wa'} that was <i>marvelous</i>. You know, {eh, eh} I'm glad this has been <i>recorded</i> 'cause this should certainly be <i>transcribed</i>. And, {uh} I know it's probably {um} <i>implicit in the paper</i>, but it was so beautifully articulated and {cl} <i>clear</i> - taking us through the issues. I {uh I re'} I really enjoyed that. {um} So, {I} I have <i>loads of comments</i>, but {I won't} I won't waste people's time {uh} going through <i>all</i> of them.

45:53 {uh} That <i>last issue</i> {i' uh, i', is} is {uh} <i>really interesting</i> about - so, the <i>meta-processor</i> or the <i>metacognitive</i> aspects of a system being able to measure <i>itself</i>. I mean there's a <i>fundamental</i> observation there that, of course, you know, {um} you <i>can't measure yourself</i>. {uh, you, you} The whole <i>point</i> of the <i>Particular Physics</i> paper was to say that, you know: "yes, there can be two kinds of information - geometries, if you like {um} and the <i>big move</i> is that one system can <i>measure</i> i.e. <i>infer</i> by possessing or having a movement {on} in some sort of information geometry, <i>infer</i> a belief update <i>about something else</i>. And so at no point is there any room for {uh} it to {sta} [Laughs] - also start to infer about its own <i>inference</i>. {uh tha, tha' that is uh you know,} that's a mathematical impossibility {from} from the <i>random dynamical system perspective</i>.

46:47 I'm not so sure about {the uh} the <i>quantum perspective</i>, but it sounds as though that's <i>also</i> true. So that <i>begs a question</i>, {um} <i>how on earth</i> do we have the <i>illusion</i> {um} that we know <i>ourselves</i>? {um} And, of course, you know {tha} that is a little bit of a <i>colloquial question</i> because, you know, 99.9% of things don't actually think that they know themselves.

47:10 So, unless there's a particular phenotype, particle or <i>species</i> that <i>boasts philosophers</i>, I'm pretty sure that most of the things that <i>exist</i> don't have {any, uh} any pretense {t'} to thinking that they know <i>themselves</i>. {Th'} It's a really interesting {uh} point to get across. <i>Anecdotally</i>, you know, I spend a lot of time {uh} taking people through examples that probably go right back to things like Ideomotor Theory, {um} that, you know, {the way that we um} the way that we develop a sense of <i>agency</i> and think that we <i>have</i> a sense of agency, you know, {is} is a gift, an illusion, that is

<i>probably</i> unique to <i>only a small number of us</i> and may <i>not even</i> be available to people with, say,
severe autism.

47:57 {um} And {the} you know, the example of that I've <i>literally in the past day just written down</i>, in a didactic way - was that; if you just take {um} <i>vanilla Active Inference under a Markov blanket</i> and then you {s' um} look at particular <i>kinds</i> of sparsity structures where the <i>active states of the Markov blanket</i> - or the holographic screen - are hidden from the internal state.

48:28 So these are special kinds of systems that have a <i>particular sparsity</i> where, now the <i>active</i> states of the Markov blanket are now - become <i>hidden</i> from the <i>internal</i> states. And, you can certainly <i>license</i> some entanglement {um} and {I would um} I would later ask about the {reg} entanglement and synchronization. So I would say entanglement or synchronization of the <i>internal</i> states such that the internal states have <i>beliefs about</i> {the'} their <i>action</i>, but those <i>beliefs</i> become beliefs about action as a <i>hidden cause</i>.

49:07 So there's absolutely <i>no notion, from the inside that you cause that</i>. You're just representing the cause. So, the example I have in mind is; you're watching a little fish swimming around, looking for food, gobbling up little bits of particles of food. And you think, "Oh! That's a very, sort of {uh}, <i>artful fish</i> with <i>purpose</i> and <i>pragmatics</i> and knows how to navigate its world."

49:32 {um} But from the point of view of the <i>fish</i>, all that is happening is that the water and the particles are moving around it in a benevolent, nurturing and fortuitous way such that the <i>water</i> is <i>delivering</i> food particles to the fish's <i>mouth</i>. So, from the <i>fish's</i> point of view, it has <i>absolutely</i> no awareness that <i>it</i> is the author or the <i>agent</i> that's <i>causing</i> this synchronization with the <i>environment</i>.

49:59 So, you know, {th' th' th'} the <i>deeper</i> question is; "how on earth do we have the illusion that we think we know {our own} <i>our own</i> agency? And how would - and when do we develop agency?" And, you know <i>furthermore</i>, it's not just agency about <i>me</i>, it's agency about <i>other things</i>. At what point do our {uh} - in our say, early neonatal neurodevelopment do we have these <i>models of the world</i> that enable us to distinguish between mother and <i>self</i>, you know?

50:31 And, at what point do we align our QRFs, if you like, with not <i>mother</i> but <i>with the world</i>? {um} That <i>enables us</i> to now see "mother" as an independent object - "so that {uh} is something else" - That is <i>an agent</i>. And, you know, the argument would then be: “well, perhaps if <i>mother is an agent</i>, perhaps <i>I am an agent</i>." And then you’ve got [inaudible] that <i>I am now</i> the author of my agency and my actions.

51:00 But {that is such} you know, that's such a <i>high-level thing</i>. I would imagine it only pertains {to, you know t’ t’} to <i>humans</i>. {That's what} That's what I say. {I'd} I'd love to talk about {um, um} the <i>homologs</i> of entanglement from a point of view of classical (inaudible) perhaps {I’ve} I’ve spoken enough, at this point.

[sp: Levin]
51:22 {Quick um j’..} Just a couple of things {uh, came} came to my mind listening to this. {um one} One is that {uh} Josh Bongard had this amazing {uh} paper in - I think it was around 2006 or so, where he had these robots and {these, they were} they started out like {uh} six-legged starfish. But {the} the cool thing about it was that they didn't have an internal model of what they were {and} or what their shape is or how to move.

51:46 And they basically had to flop around and make, {make} models of {uh} their own <i>structure</i> based on what <i>happened</i> to them, given various outputs that they generated. And eventually they would build a model of what happens and they would walk around and so on. And, two interesting things followed: one is that you could - {un} unlike traditional robotics, you could rip off one of the legs and they would very soon revise the model and keep going in <i>different</i> ways.

52:09 So they weren't tied to that particular self model, right? They would have to <i>discover it from scratch</i>, but it was still, sort of <i>plastic</i> throughout their whole lifetime. And {they could} they could get along. So they had that plasticity. And the <i>other thing</i> is that - and {um Chri, uh, Chr..} Christophe Adami wrote a nice {uh} kind of, interpretation piece of this - {he} he described {they} they spent {lots of um} lots of time being completely<i>inactive</i> and basically running through {uh} quote-unquote, “mentally running through” all the different things that they could do and what they think was going to happen {uh} <i>before they actually moved</i>. And, so you got {got Chri uh’} Chris called that, <i>“dreaming”</i>, you know, that they would basically sort of <i>play out</i> {uh, be’} before {you know} - {in be} in between their <i>actual motions</i>, when they would go around <i>testing</i> it - they would actually sort of play this out internally and try to <i>refine</i> [uh} the model, such that then when they <i>do move</i>, they would {uh} actually make movements that {uh} maximally sort of distinguish the {different} different possible models and so on.

53:00 And {he said}, you know, he said that you can watch them <i>dreaming</i> {about} about their shape. {um} So - {and} and then the other thing I just wanted to briefly mention, {this} this idea of {uh} <i>when and how</i> do you recognize that you are an <i>agent</i> and that actually you need to <i>act</i> for things to happen versus just having the environment do things to you. {I} I <i>suspect</i> that one of the things that <i>drives it very early on</i> is this {is this} notion of <i>stress</i>.

[section: “Is agency related to stress and why stress feels stressful?”]

53:23 And, {I, uh} I don't have a particular {uh, a goo-, uh} I don't have a theory of why stress <i>feels</i> stressful, but {but} just on a purely <i>functional</i> level, I think that what happens {in} in <i>cells</i> - you know, so {so} <i>very early</i>, long before you get to humans or anything like that - I think that what you get is {this um th-, this, the a} a set of mechanisms {that} that <i>evolved from</i> things like <i>stress about protein folding</i> and so on.

53:49   But then {then} basically scaled up to be <i>stress about metabolics</i>, and stress about <i>morphology</i>, and stress about <i>behavioral issues</i>, and {and} so on. That basically {is a} is a system-wide metric of {um} the <i>delta</i> between what's going on and what you'd <i>like to have going on</i>, right? The <i>delta</i> between your set point and {and} what's happening now and, {what, then} I think that drives a strengthening {of this uh of, of} of the <i>agency</i> model because what will happen is; as you {as you, as you} <i>slowly learn</i> that you can <i>do things</i> that reduce the<i>stress level</i>, it kind of <i>solidifies</i> this idea that it's actually - at least some <i>amount of it</i> - is up to you to make life better and {and} so you {then} then <i>act</i>.

54:29   And then of course, we know that breaks down in sort of learned helplessness assays and so on. That {that's that that} really is very <i>traumatic</i> {for} for all kinds of creatures well below Human.

[sp: Friston]
54:41   Can I {can I} speak to that? ‘Cause there's some <i>great</i> points there…

[sp: Knight]
54:45   Please!

[sp: Friston]
54:46 Yeah. So three <i>really</i> important things being brought to the table <i>there</i>. So, I'm bound to forget the third one if I start at the first one, I just want to … so, I'm coming back to Blue’s {um} question about, sort of, {uh um} QRFs and alignment {in that}. And, your one obvious answer that {um} one could bring to the table is that <i>learning</i> is the alignment of the QRFs.

55:09   So, learning at <i>all scales</i>. We are - and we’re talking here about developmental scales, for example; we’re talking about robots that learn to <i>repair</i> themselves or learn that new QRFs {um} if you remove a limb - or a child learning to {um} make sense of its world - then {um} you could look at the slow process of alignment of the QRFs - the things that are <i>invariant</i> over the faster time scales at {of at} which there is classical information exchange on - or, <i>in</i> -{um} a holographic {uh} screen as simply {um} a {um} <i>movement</i> from a state of {um} disentanglement to a state of entanglement {um} as you become better and better at predicting.

55:56   But to become better at <i>predicting</i>, you have to align your QRFs {you have to align that}. {um} I think {the, sort of} the <i>robot example</i> {is a perfect ex- uh} a nice illustration of that in the sense that these robots were <i>equipped</i> with {um} the ability to <i>learn about themselves</i> and of course {the, you know} the analog {um} in developmental psychology - and indeed, I would imagine developmental neurorobotics is <i>motor babbling</i>, but it's basically {you know} soliciting {um} <i>outcomes</i> – <i>sensory outcomes</i> – in order to start to disambiguate between {what} - “did I cause that or, did you cause that?”

56:34   {You know} What <i>parts</i> are apparently under my control? But of course {you know} that's a very <i>anthropomorphic</i> interpretation - there’s no my-ness or I-ness implicit. But certainly, the <i>learning of the world models</i> and {th’} the <i>body models</i>. {um} Is probably the <i>first</i> thing that <i>any</i> artifact has to <i>contend with</i> and, of course, you <i>see that</i> in children - you know, <i>shaking their rattle</i> {to} to {um um} <i>solicit</i> and {um} <i>actively solicit</i> the conjunction of visual motion, proprioceptive feedback from the muscles causing the movement of the mobile or the rattle and the auditory. So, soliciting {uh} conjunctions or correlations that are explainable and predictable {um} in multiple modalities.

57:24   So you may then ask {why on earth…} what is the imperative for that kind of behavior? What drives action to solicit this {um} opportunity to {um} <i>learn</i> the (inaudible) correlations and coincidences and the conjunctions? {um} And that brings us to the second point.

57:50   {Um um that the um} These robots <i>dreaming</i> tell you <i>immediately</i> that at some level they have an <i>internal model</i>.

58:01 of the consequences of action. {uh} And that tells you immediately that you've got (if you wanted to write that down from a point of view of classical Active Inference), you've got a belief <i>structure</i> on the inside that covers {both the covers,} both the external world and these hidden actions, and the actions upon the {of the} world, and the consequences of those actions on the external states.

58:32   That's a very sophisticated generative model to have. And you're getting now into the world of “planning as inference”. So a thermostat doesn't have that, and yet these robots do have that. So it tells you that there are two natural kinds of particles on Markov blankets or separable systems, {um} <i>at least</i> two kinds, one of which is more like a thermostat and one of which is more like {um um} a sort of {um} I was thinking of sort like an Ashby {um um} homeostat or allostat {uh but} something more like these sort of robots that can learn about about themselves.

59:09   And {the cue and} the crucial distinction, I think, is that the agent has now started to represent the consequences of its <i>actions</i>, but without realizing it's its own actions. We still haven’t got to the level of {you know} the metacognitive, “I am aware”, {kind of} kind of artifact. And {it} interestingly, it comes back to {um} what I was saying before about natural kinds, where one's active states are hidden from the internal state.

59:35 So they have to become inferred. You have to infer them {they're not they're not} they are <i>opaque</i> to the internal states. And as soon as you say it like <i>that</i>, then you're naturally talking about systems that {um} can effectively engage in <i>planning as inference</i>. So they have to have plans in their heads {uh} in order to act, which {you know} corresponds to {to and} to this dreaming.

[sp:Friston]
1:00:02 And, from the point of view of {the,uh uh, the fr-} the Active Inference, {uh} then you ask well, "what are the objective functions {um} or what are the principles of least action that would {um} <i>apply</i> to these kinds of <i>plans</i>?" And when you work it through, then one important component of {the um the sort of the} the patterns or the <i>actions</i> in question <i>is</i> a <i>drive to resolve uncertainty</i>.

1:00:32 So, we come back to this notion of the child soliciting proprioceptive, exteroceptive {um, um} <i>sensations</i> that <i>enable it</i> to resolve uncertainty. And this is <i>exactly</i> the same principle behind {Bay-} optimal Bayesian design that we <i>design experiments</i> that are going to <i>resolve the uncertainty</i> to the greatest extent <i>possible</i> under our current internal models or hypotheses about <i>how the world works</i>.

1:00:57 And that brings me to the third great point about <i>stress</i> {uh} and {the} the really <i>important</i> {um, um} <i>place</i> of stress, {and} uncertainty, {and} angst and not knowing what to do next or not knowing what's going to work, in <i>driving behavior</i>. Because, if a large chunk of the imperatives or <i>planned action</i> is to maximize information gain or {um} minimize expected <i>surprisal</i> or <i>reduce uncertainty</i>, then you can see <i>easily</i> now, why it is situations of <i>uncertainty and stress</i> that will <i>necessarily</i> {uh} cause the most {uh} <i>epistemic</i> {uh} responses in order to drive the system or, {the the uh} in this instance, the <i>agent</i> {uh} to resolve that uncertainty. The <i>final</i> point now - and this is basically paraphrasing what Mike just said [Laughs] – <i>if the system sees itself</i> behaving <i>more</i> in {s-} times of greater <i>uncertainty</i>, it may now <i>learn that</i> and now have the idea: "Oh! I am the kind of system - or, I am behaving as if I am the kind of system that responds more <i>when under stress</i>".

1:02:18 And then you'll become <i>aware</i> of that and then you can get into the psychiatric {uh} or psychological aspects of stress. You <i>may not</i> if you are just a protein, you might just show a {sort of um uh sort of} selection-for-selectability-like response. {Um but there's you know the, I think the t-, you know} The <i>two {un} fundamental mechanisms</i>, the <i>imperatives</i> that are being <i>fulfilled</i> here, <i>in accord</i> with basic conservation laws or principles of least action, from the <i>classical</i> perspective, {um, are} <i>account for exactly the same kind of behavior</i>.

1:02:46 I think the interesting thing about stress of uncertainty there, is we're talking about {the} the {um} <i>content of</i> implicit beliefs structures, but {they, the} the <i>second order statistics</i>, the <i>uncertainty</i>. {uh} And, that {'s I think, you know} brings a whole <i>level</i> of analysis to the table, because once you talk about <i>uncertainty</i> and <i>representations of uncertainty</i> {um} in, say, <i>internal states</i>. {um} Then, from a <i>psychological</i> perspective, you start to talk about <i>tension</i> and <i>consciousness</i>. {um} From the point of view of an <i>engineer</i>, we're talking about things like, <i>Kalman gain</i> and {get} getting the <i>estimates of noise levels</i>, if you like, {uh} <i>correct</i>. {um eh uh} And, {eh I'm not sure wha- [Laughs] wha-, where the, if you like the} well, <i>let me ask</i> {um} from a <i>quantum theoretic point of view</i>: is uncertainty baked into it - can you can you have a <i>stressed</i> {quantum uh} quantum formulation? I'll put that out there right - so, I'll stop talking now [Laughs].

[sp: Fields]
1:03:58 {Ye-} Yeah {uh}. Just to {just to} answer that question of {if if one} if one <i>thinks about</i> quantum theory {uh, fro'} with a <i>Bayesian view of probability</i>, right? - with the {kind of} <i>subjectivist notion of probability</i>, {um which} I mean, that point of view was really pioneered by Chris Fuchs {and} - and now David Mermin, for example, has taken it up and {uh} written some <i>very good</i> things about it - {uh} then, this notion of uncertainty <i>reduction</i> {uh} becomes the explanation for why you <i>do experiments</i> and <i>build theories</i> and {and uh} [Laughs] you know, it all becomes very <i>well aligned</i>, I think {with} with {uh} the idea of Active Inference. And, in fact, {we} we <i>wrote into that paper</i> at the very end some remark about {uh} this <i>cubist perspective</i> about quantum theory becoming a <i>result</i>, not an interpretation [Laughs]. {uh} When we think {of} of quantum theory as, <i>in a sense</i>, a way {of} of <i>reformulating the idea of Active Inference</i> {uh}.

1:05:18 So, I think they're very consistent, right? {uh a a stressed} A stressed <i>quantum</i> {is uh} - stressed quantum <i>system</i> - is just a system that gets {uh} observational outcomes and it doesn't <i>expect</i> [Inhales]. So, {you know we} we have to think of {uh} <i>such systems</i> as <i>having generative models</i> and thinking about the generative model of an <i>electron</i> [Laughs] is a bit of a <i>stretch</i>. Right? Because the electron is only <i>characterized by</i> mass, charge and angular momentum. So {uh} it <i>can't really have</i> expectations about <i>much</i>. Right? An Electron can have <i>no</i> expectations about the external electric <i>field</i>, for example. {um} It can <i>detect</i> that - it can <i>respond</i> to it - but it can't <i>predict</i> it. And, if we think about {oh} something like an electron then, we can focus-in on this <i>idea</i> that <i>having a generative model</i>, requires having enough <i>memory</i> to keep a <i>record</i> of the most recent observation - <i>at least the most recent one</i> and if you want to have a <i>good</i> generative model, then you better have enough memory to keep a record of quite a <i>number</i> of observations.

[section: "How is memory related to generative models and active inference?"]
1:07:02 And, it's this <i>memory resource</i> that really <i>simple things</i> like electrons <i>don't have</i>. So, {uh they're} they're not great <i>predictors</i> {uh} because they don't have the memory to allow being a great predictor. And, {as} as both Karl and Mike were <i>saying</i> {uh}, in a sense, {you} you have to have memory to be able to feel

<i>stress</i> {y' know}. You have to <i>know that your predictions were wrong</i> so, you have to remember what your predictions <i>were</i> [Laughs]. {uh} So, <i>memory</i> becomes a really <i>key component</i> of the <i>theory</i> {uh} once you <i>put it into</i> this <i>language</i>. {uh} Because the language, in a sense, forces you to to lay out assumptions about {what the} what the <i>computational resources</i>, that are being required, are. That wasn't very coherent but, anyway, I <i>just</i> wanted to <i>stress</i> the role of memory here.

[sp: Knight]
1:08:16 Perfect! Thank you. Karl?

[sp: Friston]
1:08:20 {Yeah d'} Just to {um} reinforce and endorse that last <i>point</i> {um} and {uh} just tell <i>exactly the same story</i> in a <i>much</i> more pragmatic way from the point of view of a <i>statistician</i>. So, <i>I heard Chris say there</i>, basically, that if I want to go <i>beyond</i> being a little electron or a <i>thermostat</i> - and I want to now {um} <i>infer the quality</i> of, "how noisy are my sensors?", for example - my thermal sensors if I'm a thermostat - that will <i>require me</i> becoming a little statistician.

1:08:52 And what does that mean? Well, basically, I'm going to be estimating the <i>standard error</i> or {the um} the experimental <i>variance</i>. There's something quite <i>important</i> about that {whic- uh, you know} which {which um uh} comes <i>back exactly</i> to the computational resources <i>and memory</i>. If you do a simple t-test as a statistician on lets say some experimental data, you necessarily have to acquire lots of data points and <i>store them</i>.

1:09:17 And, of course, <i>that</i> is <i>just</i> the degrees of <i>freedom</i> associated with {uh} your t-test or your f-test. So the degrees of <i>freedom</i> score, the number of data points that you'll be able to <i>remember</i>. And, you need a sufficient <i>number</i> in order to <i>get</i> a precise estimate of the uncertainty. So, <i>literally</i> the degrees of freedom in classical statistics is <i>literally</i> a statistic that <i>scores your confidence</i> in the estimation of the standard error which is pooled over multiple observations. Which is an attempt to estimate <i>on average</i>, if I observe with <i>this</i> kind of {um} or {I um} I asked my questions or I wrote to my holographic screen {um I} or I {um} solicited <i>these</i> sensory states, {um, you know, what would} <i>on average</i>, what would the uncertainty be, associated with it? So, I think it's a really {for} important point about the computational resources and the degrees of freedom, <i>literally</i> in the sense of the degrees of freedom associated with your f-test, <i>or</i> the degrees of freedom you have available for the computing power to actually get up to these second order inference machines or takes on the second order inference.

1:10:33 So, and I think that is particularly important when it comes back to Mike's observation about stress and uncertainty and these <i>higher order</i> ways of making sense of the world, but in this instance, making {ah} sense of sensations that are <i>accrued</i> over time, not about the content, but about the reliability or the precision of that content. So this is a really important point.

[sp: Knight]
1:11:01 Awesome, so that kind of... Oh! Chris, go ahead.

[sp: Fields]
1:11:01 {If} If I could just pick up on this and take it in, in yet another highly related direction. It's just to point out that all of these resources are <i>energetically expensive</i>. So if I'm going to devote {uh} <i>space</i> in my state space to recording memories, then that's only useful if I can defend those memories against entropy, if I can keep them from decaying.

1:11:39 So, I've got to consume energy to <i>write</i> the memories I've got to consume {energies to} energy to <i>maintain</i> the memories. And then I have to consume energy to <i>read</i> the memories and consume energy to compare what I've read with what I see with my {kind of} current-event sensors. So, as we start adding these computational resources to systems, the energy budget goes way up.

1:12:09 And {uh it's} it's another kind of <i>thing</i> to keep in mind as we think about these in terms of <i>embodied</i> forms, whether they're robots or organisms, that of these these entities are <i>extracting</i> this free energy that they have to have to run their computations and maintain their memories and all of that <i>from the environment</i>. So {here's} this is <i>another input</i> that in a sense is <i>not sensory</i>, but it's still having to <i>flow through</i> the Markov blanket.

1:12:48 It's still having to <i>flow through</i> the boundary between the system its environment and a lot of the system's <i>actions on its environment</i> - its expenditures {of} of of its own internal energy of are to <i>acquire this free energy</i>. So, you know, {we} we go out and shop for groceries, make breakfast or, whatever, all that stuff that we have to do to keep all of these processes running. So, it ties metabolism and cognition <i>together</i> in a way that they aren't often tied, but that they <i>have to be</i> to make sense of what's going.

[section: “How is free choice in an electron different from free choice in a human or an animal or a cell and, is that related to memory?”]
[sp: Knight]
1:13:36 Great! So, just on that point - something that we had written down as a question from last time and, in terms of an electron having a generative model and discussing agency, we had talked about free choice and it was brought up in the paper <i>several times</i>, both in terms of {like} <i>any physical system having free choice</i>. If <i>one</i> physical system has free choice they <i>all</i> have free choice.

1:14:03 They generate {like, their} their {um} noise generating things - like free choice generates noise in both classical and quantum systems. And so, I just was wondering if you could <i>maybe</i> say a few words about the difference in free choice in an electron and the difference {in, between} between an electron and {like} a human or an animal - or, even a cell. What is that difference? And, is that also related to memory?

[sp: Fields]
1:14:37 {Uh} Is that a question for me?

[sp: Knight]
1:14:41 A general question - for <i>anyone</i> [Laughs].

[sp: Fields]
1:14:45 Well, {I'll} I'll make a couple of comments. {Uh} One is {uh} remember, in talking about the canonical entanglement experiment {um} part of the description is that Alice and Bob can {uh} alter the directions of their detectors however they want to - at random, independently, whatever you want to call it - during the experiment. So that's the free choice assumption; or, that's called <i>in physics</i>, the free choice assumption. And, what that assumption <i>means</i>; it's <i>effectively</i> an assumption of <i>independence</i>. It <i>means</i> that there's not some common cause in the <i>past</i> that <i>determines</i> what they're going to do - as they operate their detectors.

[sp: Fields]
1:15:51 And one can reformulate quantum theory {uh} in terms of what's called superdeterminism and, superdeterminism is the idea that there <i>is</i> some common-cause in the past that <i>determines</i> how experimenters are <i>going to do</i> their experiments. And, in particular <i>determines</i> how Alice and Bob are going to rotate their detectors in this EPR experiment. And {uh} superdeterminism is kind of the ultimate non-local hidden variable [Laughs]. {uh} So, {it uh} it allows you to predict <i>exactly</i> what entangled pairs are going to do. And, in fact, it renders entanglement <i>a classical effect</i>. Right? It just says, "{these} these {kind of} <i>super-classical correlations</i> are <i>present</i> because {there} there is no independence <i>to begin with</i>. Everything was determined from the very beginning.

1:17:18 And, if you think about - {as} as mentioned last time - Newtonian physics, as formulated by <i>Laplace</i>, it's a superdetermined - deterministic - system. {uh} So, anything that happens anywhere in the universe <i>instantly affects</i> what's going on everywhere <i>else</i> in the universe. And, {the most} the most current formulation of that is Bohmian Quantum Mechanics, where the motion of any particle depends instantaneously on the motion of every other particle in the universe. And, that's how Newtonian gravity worked, right? Before Einstein imposed locality by making the speed of light finite.

1:18:03 So all of these things {are} are interconnected: assumptions about <i>spacetime</i>, assumptions about the <i>speed</i> of communication, assumptions about superdeterminism and assumptions about free choice. It's <i>that cluster of assumptions</i> that the, so-called, Free Will Theorem in Physics is about or, <i>theorems</i> there are now a couple of them {due t'} due to Conway and Kochen. And, {uh} what those theorems show is that, from a <i>formal perspective</i> {uh}, in physics; if you assume that <i>some</i> system has free choice - so, if you assume that <i>some</i> system is not subject to superdeterminism, then you have to assume that <i>all</i> systems have free choice in the sense that <i>all</i> systems are not subject to superdeterminism. So, you can't <i>limit</i> superdeterminism to some little piece of the universe and say that it only applies here. It doesn't apply anywhere else and, in particular, it doesn't apply to <i>me</i>. I have free choice even though nothing else does. That's mathematically inconsistent. So, {that's} that's {what} what the <i>free choice</i> assumption means in a strict physical context.

[Knight]
1:19:34 Thank you, very cool. Stephen - you have a question?

[section: "What can we say about "degrees" of entanglement?"]
[sp: Sillett]
1:19:41 I was just going to ask a little bit more about {the em} the <i>degrees</i> of entanglement and {um} whether that's different in terms of the observer's degrees and - versus the {like} the mechanical nature of quantum mechanics degrees. I think you've answered that to <i>some</i> extent but {uh}, {just} just the way that that varying degrees of entanglement can be thought about and whether that maybe ties into how the Hilbert space is is thought about at the same time.

[sp: Fields]
1:20:22 Yeah, {uh this} this assumption. {Uh} This question touches on why we do everything in the paper from the point of view of a bipartite decomposition. So, {we always} we always decompose into a system and its environment, in the paper.

1:20:39 {Um} And, there are two reasons for that. {uh} One is to keep it simple [Laughs]; and, the other one is to enforce the Markov blanket condition. So, {uh} it's <i>entirely commonplace</i> to do physics in an open systems framework, where we talk about {uh} two systems - we can call them Alice and Bob [Laughs], <i>again</i> that are embedded in a common environment. And, in that case, whenever you have a <i>tripartite or greater</i> - some sort of multi-particle kind of decomposition of the state space - you can talk about degrees of entanglement {uh} between different systems and you can {you know} cut up the state space any way you want to and ask about the entanglement entropy of some component of it.

1:21:41 {Uh And you} And you <i>get these ideas</i> {of} of partial - or, they call it <i>non-monogamous entanglement</i> {um} And, that's all well and good; {it's} it's <i>mathematically</i> complicated, it's <i>conceptually</i> complicated - but, {in a} in a sense it <i>deeply violates</i> the Markov blanket condition. {uh} Because, in point of fact, each of us is <i>an observer</i> and, {uh} our goal is {to} to say, "what does the world look like to <i>an observer</i>?" And, from <i>Alice's point of view</i> {uh} <i>Bob</i>, is a decomposition of <i>her Markov Blanket</i>.

1:22:35 Right? Alice has to actively <i>disambiguate</i> her incoming signals into signals that she attributes to Bob as an <i>entity</i> and signals that she attributes to the <i>rest of the environment</i> as an <i>entity</i>. So, that's an active cognitive process on <i>Alice's part</i>. {uh} That's what the Markov blanket condition - that's <i>how</i> the Markov blanket condition, in a sense, <i>forces us to think</i>. So, {uh} the mark of the condition <i>itself</i> {uh} makes us take this idea of bipartite decomposition seriously. And, {ag, ag} again, you can think of this in terms {of} of implicit assumptions about resources. {Uh} If you think in open systems terms - and so, you think of Alice Bob as as <i>Ontic entities</i> {that are} that are <i>separate from each other>/i> by a priori assumption and separate from their environments by <i>a priori assumption</i>, then you systematically underestimate the amount of <i>cognition</i> that Alice and Bob have to be doing. And so, you systematically underestimate their energy consumption. And so, you systematically underestimate {their} their <i>uncontrolled effect</i> on the <i>environment</i>. I.e. generation of waste-heat, acquisition of free-energy resources and all of that. So,it's not just a <i>philosophical difference</i>, it's a difference that leads you to make {uh} genuinely alternative predictions about things like metabolic load. So, {uh} that's why we <i>do things</i> in this bipartite framework to respect and Markov blanket condition and to {uh} keep our assumptions about energy flow explicit.

[section: “What are the implications for this for biological systems?”]
[sp: Friedman]
1:24:58 Can we take that to the latter sections in the paper about biological cognition? What are the implications for this for biological systems? Yeah - Karl?

[sp: Friston]
1:25:23 Well, {um} just to pursue that {sort of} thought experiment where you're trying to now - say, you wanted to use Active Inference to simulate Alice and Bob observing a pair of electrons - and remembering that the pair of electrons are <i>one thing</i>. So, you now got a tripartite {uh} with <i>three</i> Markov blankets in play {um} and many of the issues; for example, {um} the superdeterminism that allows some assumptions about the QRF-alignment between Bob and Alice {um, uh} to be in play, {um} and also the discussion of how {um} Alice {has to have, uh} has to contextualize sensations from <i>Bob</i>, {um} under a belief - or, an internal model, - that Bob is indeed another Markov blanket and possibly a Markov blanket very much like Alice. {uh} What you are saying is that <i>two of these particles</i>: Bob and Alice, have aligned QRFs that could have been aligned historically {uh} under the {super} - which I'd never heard of before but, I <i>like the word</i> - under superdeterminism {um} and, that may be a prerequisite to understand the experiments that we were taken through {uh} previously when looking at the <i>third</i> Markov blanket, which would be {the uh} the electron - {um, uh} or, the <i>two</i> electrons - but, for simplicity. {um} So, {uh} that from a biological perspective tells you something quite {um, uh, quite,} interesting, in the sense that it starts to get to {uh} the… {if} If it's the case that you can basically <i>carve-up</i> a bunch of states not in a bipartite way, but in a multi-partite way - and, that carving is by inserting {um} Markov blankets {uh} to <i>define the partition</i> and that every {um} - if you like, <i>subset of that space</i> now becomes internal to the third Markov blanket. So, there are now <i>no external states</i>. All we have in-play now are a set of <i>internal states</i>, each equipped with a holographic

screen or Markov blanket states that are exchanging with <i>other</i> internal states.

1:27:43 Then there's some really interesting questions about how that system will evolve {um, your} from the point of view of the discussion we've been <i>having</i>, it's going to evolve {und} under the principle of <i>unitarity</i> to entanglement. So, {it's going to from} from a classical perspective {um}, if you allow me, it's going to tend to {a, a} a state of {of uh} generalized synchronization, where everything collapses onto the same synchronization-manifold and <i>everything's indistinguishable</i> - there's <i>perfect mutual predictability</i>, there's a communication of an elemental and fundamental sort - so, everything has basically - and <i>everything</i> is singing from <i>exactly</i> the same hymn-sheet. That's the natural way of things. The Free Energy Principle is just <i>one way</i> of describing that natural tendency. {uh} What would that look like, cognitively? Well, it would <i>look as if</i> the Markov blankets we're trying to <i>learn</i> about each other and, to the extent that they can <i>act</i> on each other, they're going to try and <i>solicit</i> {um} the kinds of <i>outcomes</i> that would enable them to learn about each other. So we're now going to get a situation that is <i>driven-by</i> the imperative towards mutual predictability and entanglement. {Uh} That's an illusion. All that is actually happening is that the system is becoming entangled, But, it will <i>look as if</i> all of these separate {um um} Markov blankets or {uh, uh} sets of internal states are <i>aligning</i> in a mutually compatible way, their QRF, so that they can exchange and predict each other. And, if there's - if you like - an <i>odd man out</i>, namely the pair of <i>electrons</i>, {um} {then, you know} then there will be an asymmetry and there will be greater degrees of entanglement, {uh, you know, f' fo'} at the multiple levels, for example, {uh} if they're both observing a <i>thermostat</i>, then the thermostat is not going to be very good at learning how to align <i>its QRFs</i> with Bob and Alice, but they're all going to make the best job of it.

1:29:36 {Um} Ultimately, of course, with good cultural {nich} niche-construction, {they'll} they'll build better thermostats that will become little robots and then, they can all live happily and communicate. So, I think that's, sort of, the cognitive thing here, comes again back to <i>learning to live in your world</i> as an apparent expression of {the um} the {um}

[sp: Friston]
1:30:00 inevitable progression to entanglement whereby we try to learn about each other under the <i>plausible hypothesis</i> that, "you are like me". It's not <i>necessarily</i> true, but it {you know} it's one hypothesis you can {bring} bring to the table. You never know when it's true or not. But, that's certainly one hypothesis. It would work very nicely for Alex and Bob if they can develop a common language. So this notion of aligning QRFs between two <i>blanketed systems</i> - particles {um} that are sufficiently <i>similar</i> - {uh} then just simply translates into {um} learning {uh} to <i>share the same narrative</i>, to share the same <i>language</i>, {uh} in order to render {uh} everything mutually predictable. So I know exactly what you're going to say next, and you know exactly what I'm going to say next. And we come now to this asymptotic limit of <i>zero</i> prediction, <i>zero</i> free-energy and complete entanglement. And, that would be the {you know, the object…} we'll have <i>no Ukraines</i> or <i>Brexits</i> {or} or, anything - if we could <i>get</i> there [Laughs]. {uh} But that would be the

{you know the} direction of travel from a biological perspective. And, {just, just to that} there are simulations of this from a purely classical {uh} perspective, {Um, sta’} and what you normally do {um} is start off with {um} two systems {um} that <i>think</i> they have {um} strange attractors - usually a Lorenz attractor.

[sp: Friston]
1:31:30 So, they <i>think</i> that the dynamics {um} are generated by the act {the th’} autonomous - or, the active states - create stuff out there that {uh} has {uh a} a <i>chaotic</i> aspect. And, {I ,I} I say that explicitly just because the {sort of} the notion of free will and choice in the <i>classical</i> domain usually reduces to sensitivity due to initial conditions, which strikes me as a homolog of the superdeterminism - {going, you know} can you go right back to the <i>beginning</i> and {um} explain everything. {Um, uh} And, in {sort of} classical dynamical systems, there are certain situations where you <i>can't</i> because you get {uh} sensitivity to initial conditions. {Uh} So, that would leave <i>space</i> for {uh} free will and choice {uh} that is, certainty, {at a} at one level. But sorry, I digress. {they uh} So, what you do is you, basically, put {sort of} two chaotic systems with sensitivity to initial conditions together, {uh} but they're not identical in the first instance.

[sp: Friston]
1:32:30 But, if they can <i>exchange</i> sensory and active states, or they can exchange across a <i>shared holographic screen</i>. So we're now back to the <i>bipartite</i> situation. Then, they will <i>naturally</i> - and, in fact, if you think about it they can't do anything else - {um} they will naturally {uh} come to a state of entanglement, i.e. {and if uh uh} <i>generalized synchrony</i>. And, if you allow the <i>parameters</i> of the equations of motion that underwrite these chaotic {dynamic, uh} dynamics to also maximize mutual predictability or minimize free-energy then they will actually come to show an <i>identical synchronization</i> because they will <i>learn</i> to become like each other <i>just like</i> Miike’s robots.

[sp: Friston]
1:33:11 {Uh} But, in this instance, they're learning about the <i>other</i> person <i>simply to make things predictable</i>. So, then you will have a shared narrative. And, <i>in principle</i> {uh} you should be able to evince a kind of language - and, {I, I} I <i>mentioned that</i> because I know Chris wanted to talk about {lang’} - and, we wanted to talk about {you know, quant} quantum physics is just basically a description of communication and language. {uh, I don't} I don't think that I have time to do that, but I thought I’d slip that in anyway. [Laughs.]

[sp: Knight]
1:33:40 Chris, did you want to say a few words? Quantum and language.

[section: “How is local entanglement like a language?”]
[sp: Fields]
1:33:49 Oh, well, {that was} that was <i>lovely</i>, Karl! And, {I} I like the <i>idea</i> of this kind of simulation, leading {to} to generalize synchrony. I think it's interesting from this perspective that {we uh} we always divide our environment into <i>entities like us</i> and then

at least one entity that's radically <i>unlike us</i>, which we call the shared environment or {the} the open environment, the general environment or something like that.

1:34:30 And, {uh} so we have this sense of {a} a <i>social grouping</i> of similar entities {uh} that are commonly exposed to this <i>vastly dissimilar</i> entity with which we <i>don't</i> share a common language - {Uh} and, we're not very good at predicting {Uh} and so on. And so, we always have this {kind of} open systems point of view. And, {uh} one of the functions of this vastly different system with which we don't share a common language is: it's our free energy source and sink. So, it's where we put our waste heat and, {it's} it's where we get our free-energy for doing computation.

1:35:28 {uh} So, {I} I think it's interesting to think of {uh} this situation of {uh, kind of} <i>local synchrony</i> {or} or <i>local entanglement</i> or a <i>local language community</i>, {uh} <i>local shared predictability</i>, {uh} embedded in {uh} this unpredictable {uh} chaotic - and, in a sense, <i>in principle</i> chaotic - because, it's the waste heat dump, right?. {Uh} We've assumed <i>a priori</i> that we can't understand it because it's where we're putting {uh} all of our - the thermodynamic entropy that we're creating. {uh we we've} We've put ourselves in a conceptual bind <i>almost automatically</i> by being systems {that} that have to generate this entropy and put it somewhere. So, I like {this} this classical-to-quantum correspondence very much, and {I th'} I think it works very nicely.

[sp: Knight]
1:36:41 Awesome! Mike?

[sp: Levin]
1:36:42 Yeah, {um, I want to} I want to float an idea which is literally just a few days old, so it may be {uh} complete nonsense. But, {I'll} I'll float it anyway because {I think it's uh} I think it's {it's} relevant and, {I'v} I've been thinking about it this way. It occurs to me that {um you know this} this binary distinction between: {uh} there are <i>agents</i> - some of them <i>like me</i>, some of them <i>different</i>, maybe competitors, whatever. But, they're there are some agents that I can communicate with or can I receive influence or signals from - {and then} and then there's this <i>environment</i> which is {you know} something that we assume - or, I mean, {some} some cultures don't want to assume that - {but} but we can assume that it has very low or zero agency, meaning that it just is the sort of dumb {unp'}, purposeless universe and it's on us to {sort of} figure out what it's doing, right.

[section: "What is the difference in approach and experience of "training" vs. "learning?"]
1:37:33 So, {it} it occurs to me {that} that that distinction maybe shouldn't be binary and, maybe what we want to be thinking about is; <i>as an agent</i> - when you are receiving something {uh from} from what you think is the outside, you might want to estimate {uh ha' wha'}, "what is the agency on the other end?" {for the, and} And, you might want to do this for the following reason, right? And, {I} I started thinking about this by imagining what it would be like to be in an internal partition or a chunk of a giant neural net being trained, {you know, you}

you live - if that's you - you live in a very mindful universe. {you know} You could catch on to the fact that: “you know what, I'm being <i>trained</i> for something.”

1:38:12 You know, the world - like, there are bigger patterns here. And of course, it moves in inscrutable ways and everything because I can't {you know}, I can't sort of I can't understand the <i>whole</i> pattern of what's going on. But I can <i>definitely tell</i> that it's rewarding me and punishing me for specific behaviors. Right? And, of course, some people do feel that way about the universe - and writ-large - in that there are patterns {that are} that are not just, {you know, not} quote-unquote, <i>just physics</i>.

1:38:33 And {so} so, {the reason} the reason {I} I think and this extends to - you know, we have supervised learning and unsupervised learning. And again, we think of those as {kind of} binary things, right? Is there some sort of intelligence on the other end telling you what's right and wrong or is it just on you to abstract patterns from the environment? And, the reason I think {we} {th’} this matters is that {if, if, uh, if} if you are {uh} trying to learn from the environment - meaning there's only one agent involved, “there's {right? there’s} that’s you - there’s one agent - and then there's this sort of unthinking universe around you. Then, you are pretty much guaranteed that {whatever uh} whatever you can manage to infer, {to} it will be to your utility. It's on you to figure out {uh y’} - to learn whatever you can. If there's another agent on the other side and you are being <i>trained</i>, right? Then {uh}, what are the odds that that agent has your best interests at heart? I mean, <i>maybe</i>, but maybe not. And so, if this is some sort of supervised learning, you have to ask yourself, {w’} what is it that I'm being trained? And, is it really {what I} what I want?

1:39:36 Right? {There’s} There’s another {its’} - it’s kind of a whole thing that you can imagine, evolutionarily, that maybe to avoid {uh} being hijacked {by uh by by, by} by parasites, {by} by {you know} competitors, by whoever - you don't really <i>want to be trainable</i>, too much. You want to learn, but you don't really want to be trained. And so, maybe, the idea then is that {uh, what if} what if - and, {this is, okay} this is where {you know} I really {haven’t} haven't {uh} talked to anybody about this yet. So {this is} this, again, could be {uh} very amateurish stuff. {But} But what if something like back propagation, or whatever? What if that literally <i>hurts</i>? What if {as a, as a, right?} as an early creature having some sort of error function forced back through your channels as opposed to whatever you were trying to generate yourself? What if that's evolutionarily designed to be unpleasant?

1:40:26 And, what if what you're trying to do is avoid that happening? You don't want to be trained; you want to {uh} learn on your own terms. And, you could sort of imagine the different layers of a feed-forward artificial neural network where the {like the} initial input layer {tha’} that {be’ that be’, sort of} creature gets to see the world, quote-unquote, “as it is”. It gets the raw inputs. The <i>next layer</i> and certainly the layers <i>past that</i>, you know, the ones {on the, right? } that are {ab} abstracting, they're getting all kinds of propaganda filtered to them by the early layers. {you know} They don't get to see the real inputs; they get to see whatever the {pre} the prior layers <i>think</i> they should be seeing.

1:41:04 {And} And so, maybe if you don't have a flat network like this, but maybe what you have is a {um, you know} - more biologically - you have a {uh} kind of a nested {uh, uh} multiscale kind of system. Maybe, there's some sort of {uh} incentive for the middle layers to try to {sort of} crawl leftward so that they have more raw access to the real world and not be trapped {uh being} being fed by these other agents. Right? So again, {you know} this is all very qualitative stuff, but you get the idea - that's {that's kind of what uh wha'} what I was thinking about.

[sp: Knight]
1:41:39 Nice! Dean, and then Daniel.

[section: "What do we do when we look at things in a relational realm?"]
[sp: Tickles]
1:41:45 Mike, if you want to chat about this, this is what I was doing for about ten years - unleashing and getting out of the lab and getting past the toy model. So, perhaps we should chat about this for a bit. {Uh can I just} A couple of things, {uh} Chris. First of all, thank you for {uh} - I feel like I've come away with a Munich-stein-volume worth {of} of coolness for the last two weeks just listening to you explain these really {comp', well} complicated things to me in ways that I can actually understand. Um} One of the things that {I'm} I'm still kind of curious about is; once we let things out of the lab and we keep them in that variability-routine space - and {we're and} we don't want to be in conflict with {sort of} the basic rules of what quantum information tells us. I want to {kind of} go back for one second to what Steven was {kind of} closing the 40.1 with - and that is: what do we do when we look at things {in} in that {sort of} relational realm that a lot of {um in, in du'} indigenous cultures {sort of} take up and try to find themselves within and I'm {kind of ge'} leading to this idea that {there's} there's a {sort of a} subject-matter generalist that leads to a prediction-matter expert, down the road. And {I}, I talked to Karl - I have - it was my question to Karl, back in June, when he was talking to us in the Active Inference Lab.

1:43:16 And so, without getting into any kind of conflict with the quantum aspects of this, {um what, what} what do we take out {with} with us when we go on a bike ride {with} with Chris Fields {that's} that's quantum related, that isn't in conflict with everything we've talked about today but gives us a better confidence around the things that we might encounter and predict.

[sp: Friedman]
1:43:47 What do you take on your bike, Chris?

[sp: Tickles]
1:43:50 Yeah. What's in your quiver?. [Laughs]

[sp: Fields]
1:43:53 Yeah! {uh} Good question! {uh, you know} Once again, {these} these theoretical frameworks <i>are languages</i> and {they} their role is to shape our <i>concepts</i> or

{they're} they are ways of shaping our concepts. And, {um} {I th} I think the fundamental {kind of} lesson of quantum theory for us is to: not take the boundaries we see {uh} as <i>literally</i> as we're encouraged to do in the classical worldview. {I'll} I'll try to distinguish the classical world view from classical physics, because classical physics <i>by itself</i> - again, going back to someone like Laplace {uh} - is a physics of {of} atoms [Laughs] {which are}, which are {you know} sort of elemental. {Uh} It's not a physics of bounded macroscopic objects. The boundaries - even in classical physics - are {sort of} arbitrary and {I} I think that's what quantum theory is trying to tell us {to} - is trying to tell us; that {these} these are boundaries that we draw on <i>our blankets</i>.

1:45:49 And, I think this is, in a sense, what {uh} thinking about the FEP is trying to tell us. {That} That we have to take this notion that we're blanketed entities <i>seriously</i> when we think about what we're interacting with - which is {you know} everything but us.

[sp: Knight]
1:46:16 Daniel?

[sp: Friedman]
1:46:20 In our closing minutes, {um} if we could just each give a thought, this is really just a special and very powerful {uh} conversation {uh}, Mike, {uh} with a back-propaganda. Amazing thought experiments there. And {uh} no boundary and quantum questions touching on the work of, {like} Ken Wilbur. And, I think it's just so powerful about {um} - does someone have the whole world in their hands? Is that a <i>good</i> person? Is it a <i>bad</i> person or thing? What kind of thing is that? Who's on the other side of this video call? Who's on the other side of that other side? What's the bigger picture? And, it really brings it home that, “no, it's not just about electrons. This is something that is across scales and systems”. So - really just wanted to appreciate the paper - and, hope that we {uh} continue on this line of development. And, I'll pass to Stephen.

[sp: Sillett]
1:47:29 {Uh} Thanks, Daniel. Yeah, I was going to try this a little bit - some of the threads - with {um} this challenge of having this false sense of certainty in our culture. And, it does feel uncomfortable to be <i>trained</i> {um}, but we do it in the West because we're confident that we've got this expert knowledge, but then we suddenly find that we don't know as much as we do know - or we <i>think</i> we know. So, that may be why bottom-up {sort of} organic, indigenous {kind of} ways of being or, ways of sensing, can feel more holistic. So, I think there might be something quite powerful in that. So, I like that thread and I think that ties together with {um} the challenges, in practice, when we try {to} to train-up community - especially if we're working - say, with our work in rural Africa - and communities there {tha'} - if they don't feel connected to {the} the <i>colonizing narrative</i>, it feels very oppressive. So, {there's you know} there's a lot of good points there around, “where is there coherence? Where is this decoherence? And, also, “where is there certainty and where there's uncertainty?” So, thanks. This is really helpful and {um} I'll pass it over to Bleu.

[section: “What are your final thoughts? What are you each taking away from the discussions we've had over the last couple of weeks?”]
[sp: Knight]
1:48:54 Well, <i>I've said enough</i>. I think {uh} I'd like to hear from Mike or Karl or Chris about {where} where you're going or what you're taking away, or what are your final thoughts about discussions we've had over the last couple of weeks.

[sp: Levin]
1:49:10 I mean, {I guess} I guess the only thing I'll say is that {uh}, to me - {I} I really like {um} this idea that {it} it turns on its head. {This} This notion {that uh} that you have {this this} this massive amount of {uh} mindless stuff and then, somehow, {you know} a little bit of mine shows up at the end that {that kind of} turns it upside down. And, {and} if that's the case, then it becomes - {the’} then the scaling problem is {is} really, really interesting, right? Is {how} how you scale - {you know how} how biology manages to scale these things so that they become {synergis’} synergistic and bigger and bigger as opposed to {you know} just merely a bigger pile of rocks {than} than the previous pile of rocks. And so, {that uh, right so so those} those mechanisms - and, in particular in biology - and so, {you know} I look at it {from} from cells getting together to be organisms and solving problems in the anatomical space.

[sp: Levin]
1:49:57 {But} But I think, there, we actually have {uh} some pretty good {um} alternative - {uh alth’} although {very, very uh} very similar - in many ways isomorphic - but, alternative stories to what happens in neuroscience to try to understand how that scaling actually works. So, I'm super - I'm just super, super excited about that. And, also the role of the observer in all of this and the idea that all of this is based on various observers observing each other. And, I think that makes - {it} it makes for a lot of progress {and} and fewer pseudo problems, {when you} when you look at it that way.

[sp: Knight]
1:50:31 Karl or Chris, any final thoughts?

[sp: Fields]
1:50:39 Well, {I’ll} I'll just thank you guys again for putting this together. I thought this was a <i>fascinating</i> conversation and, {uh you know} if I could throw one more thing into it, {I, I} I think conversations like this {are} are <i>evidence</i> for {uh the} the kind of disciplinary siloization that's been forced onto us by academic tradition, being an artifact and not necessarily being all that useful

[sp: Knight]
1:51:21 Thanks so much. Karl, we're going to leave you with the final word go ahead.

[sp: Friston]
1:51:26 {Uh} Good, well, [Laughs] there has to be a, “thank you” doesn’t here {um}- for you lot putting this together and for the brilliant didactic and, also challenging {uh} didactic {uh}

unpacking of some really {um} challenging, but I think revealing issues and also the brilliant questions. {um} My final word will be <i>future-pointing</i>. And, {um just} just {taking up um} taking up this lead of Chris' {you know} that having un-siloed conversations is useful - just {think} thinking about Mike having the balls to come out with his brand new hypotheses that's two years so, - two <i>days</i> old Mike! [Laughs] So, I thought it was really interesting {to say} and, a nice <i>example</i> of putting things into this kind of discussion which are all going to go away and think about. So, my <i>immediate</i> thought was {um}, "how on earth does the second layer in a variational autoencoder - or, something doing back-prop - act? And, of course, it <i>can act</i> {if} if it's a <i>recurrent</i> neural network and it can <i>select</i> which of {the uh} the lowest-level neurons or hidden-layer - {uh} sorry, {no'} non-hidden-layer {uh} units {uh} to listen to. {um} And, of course, we come back again exactly to attention and selecting those sources of precise information {um} where you've got a kind of internal action. So, {th' uh} an interesting and silly thought, but just a nice example of how talking together {ca'} can excite interesting {and, and} and {uh} potentially useful or, possibly {silly} silly thoughts. Well, again, thank you.

[sp: Knight]
1:53:02 Wonderful. I had a great time observing all of you {um} and hope to get to do more of it in the future.

[sp: Friedman]
1:53:10 Yep, we can have a dot-three any time. Consider 40 {um} in the {uh} inter-measurement interval while our Igus is digesting and, {uh} talk to you all soon, thanks again.

[sp: Fields]
1:53:28 Thanks very much, everyone. Thank you.

[sp: Friedman]
1:53:29 Bye

[sp: Knight]
1:53:30 Bye bye.

[sp: Fields]
That was great.