A COMPUTATIONAL GUT

Giacomo Mauro D’Ariano

Dipartimento di Fisica “A. Volta”, Università di Pavia

arXiv: 1001.1088
WHY QUANTUM?

Is there something more than Quantum?

RELATIVITY?

QFT?

Quantization rules, $\hbar$?
POSSIBLE ANSWER: THE UNIVERSE IS A HUGE QUANTUM COMPUTER.
HOW RELATIVITY EMERGES FROM THE COMPUTATION?
Lorentz transformations from Galileo principle

Galileo principle includes homogeneity and isotropy of space and homogeneity of time.

On the assumption of isotropy and homogeneity of space and homogeneity of time along with symmetry between the two references, the most general transformations of reference system are the Lorentz transformations with a parameter $\Omega$ with the dimensions of a velocity, which is independent on the relative velocity of frames.

Empirically $\Omega = c$, which is an upper bound for velocities.
Special Relativity from computational network

* Take a computational circuit which is uniform and isotropic.
* Take the “continuum limit” $\rightarrow$ space-time.
* Take only finite-system gates $\rightarrow$ bound on speeds $\blacksquare$. 
superluminal

luminal

subluminal
Relativity from QT
(more generally from causality)

causal antichain

Input → Output

causal chain

causal antichain

systems

topology

no metric

only event-counting

causal immediateness

causal propinquity

slice

chain (time)

antichain (space)
Relativity from QT

build a uniform foliation
Relativity from QT

can be a change in reference
Relativity from QT

speed of light
Relativity from QT
Relativity from QT
Relativity from QT
WE GOT SR FROM PURE CAUSALITY!
The Operational Framework

*Probabilistic operational theory:* every test from the trivial system to the trivial system is associated to a probability distribution of outcomes.
A theory is causal, if for any two tests that are connected the marginal probability of the input event is independent on the choice of the output test, whereas, vice versa the marginal probability of the output event generally depends on the choice of the input test.
Wittgenstein-ism

1 The world is all that is the case.
   1.1 The world is the totality of facts, not of things.
      1.11 The world is determined by the facts, and by their being all the facts.
      1.12 For the totality of facts determines what is the case, and also whatever is not the case.
      1.13 The facts in logical space are the world.
   1.2 The world divides into facts.
      1.21 Each item can be the case or not the case while everything else remains the same.
My Brief History of Space-Time

At the beginning there were only events ...

Then the Man devised causal connections between them

He modeled the causal connections in a unified framework which is space-time
Quantum Computational Field Theory (QCFT)

\[ H = \sum_{\langle i,j \rangle} H_{i,j} \]

\[ \phi(0) \quad \phi(t) = U_t^\dagger \phi(0) U_t \]

\[ U_t = \exp \left( -\frac{i}{\hbar} \tau \omega H \right) \]
QCFT

p nn translational-invariant “Hamiltonian”

\[ H = \sum_{k=0}^{p-1} H^{(k)}, \quad H^{(k)} = \sum_{i=-N_x}^{N_x} H_i^{(k)} \]

\[ [H^{(k)}, H^{(l)}] = 0, \quad [H^{(l)}, H^{(k)}] \neq 0 \]
Using the Trotter's formula

\[
\lim_{N \to \infty} \left( e^{-i \frac{tH}{N}} e^{-i \frac{H(1)}{N}} \ldots e^{-i \frac{H(p-1)}{N}} \right)^N = e^{-i \omega t H}
\]
where we used the notation comes an operator obeying the following equal-time anticommutation relations:

\[
\{ \sigma_\alpha, \sigma_\beta \} = 2 \delta_{\alpha \beta} \sigma_0
\]

In the computational representation—the field operator can be written in terms of local operators,

\[
\psi_n = \sum_n \sqrt{\frac{2}{L}} e^{i n x} \psi_n(x)
\]

One has

\[
\langle \phi \mid H^{(l)} \mid \phi \rangle = 0
\]

Consider the unitary transformation from the uniform Hamiltonian with

\[
H = \sum_{k=0}^{p-1} H^{(k)}, \quad H^{(k)} = \sum_{i=-N_x}^{N_x} H_i^{(k)}
\]

\[
[H_i^{(k)}, H_j^{(k)}] = 0, \quad [H^{(l)}, H^{(k)}] \neq 0
\]

(Ichinose and Tamura bound)

\[
\left\| e^{-i \omega t H} - \left( e^{-i \omega t H^{(0)}} e^{-i \omega t H^{(1)}} \ldots e^{-i \omega t H^{(p-1)}} \right)^N \right\| \leq O(N^{-1})
\]
SIMULATING QFT

Simple scalar fields in 1 space dimension

- space-granularity (minimal in principle discrimination between independent events);
- time-granularity;
- \( \phi(x) \) field, operator function of space (evolving in time); we will describe it by the set of operators \( \phi_n := a^{\frac{1}{2}} \phi(na) \)

\( \phi_n \) generally nonlocal operators. In QFT they satisfy (anti)commutation relations

**Equal-time microcausality:**

**Fermion:** \( \psi \) \( \{ \psi_n, \psi_m \} = \delta_{nm} \) (Dirac)

**Boson:** \( \varphi \) \( [\varphi_n, \varphi_m] = \delta_{nm} \) (Newton-Wigner)
SIMULATING QFT

Simple scalar fields in 1 space dimension

Time evolution: \( \phi(t) = U_t^\dagger \phi(0) U_t \)

\[
U_t = \exp \left( -\frac{i}{\hbar} t \hbar \omega H \right) = \exp(-2\pi i N_T H)
\]

\( H \): adimensional Hamiltonian

\[
N_T = \frac{t}{T} = \frac{\omega t}{2\pi}
\]

\[
i\hbar \partial_t \phi_n = [\phi_n, \hbar \omega H]
\]
**SIMULATING QFT**

*Klein-Gordon* in 1 space dimension

\[
H_s = -s \frac{i}{2} \sum_n \left( \phi_n^{(s)\dagger} \phi_{n+1}^{(s)} - \phi_{n+1}^{(s)} \phi_n^{(s)\dagger} \right) = s \frac{a}{\hbar} P,
\]

\(s = \pm 1\)

\[\phi_n := a^{\frac{1}{2}} \phi(na)\]

\[P = -i\hbar \int dx \phi^\dagger(x) \partial_x \phi(x)\]

\[\phi^{(s)}(x), H_s = \left[ a^{-\frac{1}{2}} \phi^{(s)}, H_s \right] = -a^{-\frac{1}{2}} s \frac{i}{2} (\phi_{n+1}^{(s)} - \phi_{n-1}^{(s)}) = -is a \partial_x \phi^{(s)}(x)\]

\[\omega a = c\]

\[\square \phi = 0\]

Both for Bose and Fermi fields (using: \([AB, C] = A[B, C]_{\pm} \mp [A, C]_{\pm} B\))
**SIMULATING QFT**

**Klein-Gordon in 1 space dimension**

**Trotter-ization**

\[ U_t = e^{-i\omega tH} = \lim_{N \to \infty} U_t^{(N)}, \quad U_t^{(N)} := \left[ \prod_l e^{-\frac{it}{2N\tau} H_{2l-1,2l}} \right] \left( \prod_l e^{-\frac{it}{2N\tau} H_{2l,2l+1}} \right)^N \]

\[ H_{n,n+1} = \mp \frac{\pi i}{4} \left( \phi_n^{(s)} \phi_n^{(s)\dagger} - \phi_{n+1}^{(s)} \phi_n^{(s)\dagger} \right) \]

renormalized coupling

\[ \mathcal{V}_{\text{caus}} = \frac{a}{\tau} = c \quad \Rightarrow \quad \frac{L}{t} = \frac{2N_x a}{2N\tau} = c \quad \Rightarrow \quad N_x = N \]

swapping gate

\[ 2\pi N_T / N = \pi \]

\[ \omega a = c, \quad a = \frac{cT}{2\pi}, \quad \tau = \frac{T}{2\pi}, \quad t = 2N\tau. \]
**SIMULATING QFT**

*Dirac in 1 space dimension*

\[ i\hbar \partial_t \psi = \left( \begin{array}{cc} ic\hbar \sigma_x \partial_x & mc^2 \\ mc^2 & -ic\hbar \sigma_x \partial_x \end{array} \right) \psi, \quad \psi(x) = \begin{pmatrix} \psi_1(x) \\ \psi_2(x) \\ \psi_3(x) \\ \psi_4(x) \end{pmatrix} := \begin{pmatrix} u(x) \\ v(x) \end{pmatrix}, \]

Field equal-time commutation relations (quantization rules)

\[ \{ \psi^\alpha(x), \psi^{\dagger \beta}(y) \} = \delta_{\alpha\beta} \delta(x - y), \quad \{ \psi^\alpha(x), \psi^\beta(y) \} = 0. \]

Hamiltonian:

\[ \hbar \omega H = \int dx \psi^{\dagger}(x) \left( \begin{array}{cc} ic\hbar \sigma_x \partial_x & mc^2 \\ mc^2 & -ic\hbar \sigma_x \partial_x \end{array} \right) \psi(x) \]
SIMULATING QFT

**Dirac in 1 space dimension**

**QCFT**

\[ \psi_n^\alpha = a^\frac{1}{2} \psi^\alpha (na) \]

\[ \psi_n^\alpha = \Gamma_{4n+\alpha}, \quad \Gamma_k := \left( \prod_{j=-\infty}^{k-1} \sigma_j^z \right) \sigma_k^-, \quad \{ \Gamma_k, \Gamma_h \} = \delta_{kh} \]

\[ i\hbar \partial_t \psi_n = [\psi_n, \hbar \omega H] \]
SIMULATING QFT

**Dirac in 1 space dimension**

**QCFT**

for \( \omega a = c \)

using the identity

\[
\begin{bmatrix}
\sum_{n_\alpha} \psi_n^{\alpha \dagger} K \psi_n^{\alpha}, \psi_l^\beta
\end{bmatrix} = - \sum_{n_\alpha} \{ \psi_n^{\alpha \dagger}, \psi_l^\beta \} K \psi_n^{\alpha} = - K \psi_l^{\beta}
\]

\[
H = \sum_{n_\alpha} \psi_n^{\dagger} \left( \begin{array}{cc}
\frac{i}{2} \sigma_x (\delta_+ - \delta_-) & \frac{a}{\lambda} I \\
\frac{a}{\lambda} I & - \frac{i}{2} \sigma_x (\delta_+ - \delta_-)
\end{array} \right) \psi_n^{\alpha}
\]

\[
\lambda := \frac{\hbar}{mc} = 3.86159 \times 10^{-13}
\]

**Compton wavelength**

\( \partial_x \) makes sense above the scale of \( \lambda \)

\[
u \text{ and } \nu_n \text{ for full QCFT along with the fact that for commuting Hermitian operators}
\]

\( \sum_{n} \psi_n^{\alpha \dagger} K \psi_n^{\alpha} \psi_l^\beta \)
Using the identity which, for one obtains $\phi^\dagger \bar{\phi}$.

One has $t = x \sum_i U_i \phi_i - n \phi_i \omega_i$, $t = t H N_s - \phi_i \omega_i$, $\lim_{s \to \infty} = \phi s 
\phi \omega = H N_s - \phi \omega = H N_s - \phi \omega$

$\phi \omega = H N_s - \phi \omega$, $\phi \omega = H N_s - \phi \omega$, $\phi \omega = H N_s - \phi \omega$

Circuit for the Hamiltonian 385 for the Dirac field.

It is interesting to notice how a motion of the particle will manifest as a zigzag motion linking the full circles represent the blocks.

Such motion is usually explained as an interaction of the classical particle with the zero-point field.
SIMULATING QFT

Dirac in 1 space dimension

\[ |\psi_n^1\rangle := \psi_n^{1\dag} |0\rangle \]

\[ \psi_n^{1\dag} = (\prod_{j=-\infty}^{4n} \sigma_j^z) \sigma_{4n+1}^+ \]

"particle" creation

antiparticle

particle spin-up and spin down

Such motion is usually explained as an interaction of the classical particle with the zero-point field. Schrödinger’s motion is usually explained as an interaction of the classical particle with the zero-point field. The Dirac particle experiences a fluctuation at the quantum level, represented by the formula above, which describes the creation or annihilation of a particle.
Zitterbewegung
SIMULATING QFT

\[ \psi_{n}^{\alpha} = \Gamma_{4n+\alpha}, \quad \Gamma_{k} := \left( \prod_{j=-\infty}^{k-1} \sigma_{j}^{z} \right) \sigma_{k}^{-} \]

\[ H = \sum_{n,\alpha} \psi_{n}^{\dagger} \left[ \left( \frac{i}{2} \sigma_{x}(\delta_{+} - \delta_{-}) \right) - i \frac{a}{\lambda} I \right] \psi_{n}\alpha \]

\[ \sigma_{k}^{+} \sigma_{k+1} \sigma_{k+2} \cdots \sigma_{k+l-1} \sigma_{k+l}^{-} \]

\[ \sigma_{h}^{+} \sigma_{h+1} \sigma_{h+2} \cdots \sigma_{h+l-1} \sigma_{h+l}^{-} \]

\[ |\psi_{n}^{1}\rangle := \psi_{n}^{1\dagger} |0\rangle \quad |0\rangle := \begin{array}{c} \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \end{array} \]

**ONLY QUBITS! NO MORE FIELDS! NO MORE QUANTIZATION RULES!**
QCFT OF DIRAC

1 space dimension

\[ \zeta^1 = \sigma^-, \quad \zeta^2 = \sigma_1 \sigma_2^-, \quad \zeta^3 = \sigma_1^z \sigma_2^z \sigma_3^-, \quad \zeta^4 = \sigma_1^z \sigma_2^z \sigma_3^z \sigma_4^-, \quad \zeta^5 = \sigma_1^z \sigma_2^z \sigma_3^z \sigma_4^z \]

\[ (\zeta^5)^2 = I, \quad \{\zeta^i, \zeta^j\} = 0, \quad \{\zeta^i, \zeta^{j\dagger}\} = \delta_{ij}, \quad i, j = 1, \ldots, 4 \]

\[
H_{n,n+1} = \frac{\pi}{2} \begin{pmatrix}
\zeta_1 \\
\zeta_2 \\
\zeta_3 \\
\zeta_4 \\
\zeta_n
\end{pmatrix}^\dagger \begin{pmatrix}
0 & i\Gamma \Delta & \gamma & 0 \\
i\Gamma \Delta & 0 & 0 & \gamma \\
\gamma & 0 & 0 & -i\Gamma \Delta \\
0 & \gamma & -i\Gamma \Delta & 0
\end{pmatrix} \begin{pmatrix}
\zeta_1 \\
\zeta_2 \\
\zeta_3 \\
\zeta_4 \\
\zeta_n
\end{pmatrix}
\]

\[ \Delta := \frac{1}{2}(\delta_- + \delta) \]

\[ |0\rangle := \cdots \underbrace{\uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \uparrow \downarrow \cdots}_{n-1 \quad n \quad n+1} \]
QCFT OF DIRAC

Recovering QFT from QCFT

\[ H_{n,n+1} = \frac{\pi}{2} \begin{pmatrix} \zeta_1^1 & \zeta_2^2 & \zeta_3^3 & \zeta_4^4 \end{pmatrix} \begin{pmatrix} 0 & i\Gamma\overrightarrow{\Delta} & \gamma & 0 \\ i\Gamma\overleftarrow{\Delta} & 0 & 0 & \gamma \\ \gamma & 0 & 0 & -i\Gamma\overrightarrow{\Delta} \\ 0 & \gamma & -i\Gamma\overleftarrow{\Delta} & 0 \end{pmatrix} \begin{pmatrix} \zeta_1^n \\ \zeta_2^n \\ \zeta_3^n \\ \zeta_4^n \end{pmatrix} \]

Recovering QFT for \( t \gg \tau \) and \( x \gg \lambda \)

\[ \psi_n^\alpha = \left( \prod_{j=-\infty}^{n-1} \zeta_j^5 \right) \zeta_n^\alpha \quad c = \frac{a}{\tau} \quad \hbar = \Gamma\tau \quad mc^2 = \gamma \]

\[ \frac{1}{2a}(\delta_+ - \delta_-) = \partial_x, \quad \frac{1}{2}(\delta_+ + \delta_-) = 1. \quad \mathcal{O}(a^2) \]
The Zitterbewegung provides the new intuitive picture.

The new “particles” move at the speed of light: the mass is the coupling with the antiparticle, and the interaction produces the “slow-down”.

The field description gives a “classical” description in terms of harmonic oscillation with bilinear Hamiltonian

quantization rules “emergent”

no causality leakage nor localization problems
SIMULATING QFT

Dirac in 3 space dimensions?
$|\phi(x)\rangle := \phi^\dagger(x)|0\rangle$ single particle at position $x$

$|\phi_n\rangle := \phi_n^\dagger|0\rangle$ qubit↑ at $n$ (or 1 boson at $n$)

$i\hbar \partial_t |\phi_n\rangle = [\phi_n^\dagger, \hbar \omega H]|0\rangle = -\hbar \omega H |\phi_n\rangle$

$i\hbar \partial_t \langle \phi_n | \Phi \rangle = \hbar \omega \langle \phi_n | H | \Phi \rangle = \hbar \omega (H \Phi)_n$

$$
\Phi = \begin{pmatrix} 
\Phi_n \\
\Phi_{n+1} \\
\vdots 
\end{pmatrix}, \quad \Phi_n = \langle \phi_n | \Phi \rangle, \quad H = \begin{pmatrix} 
\cdots & \langle \phi_n | H | \phi_m \rangle & \langle \phi_n | H | \phi_{m+1} \rangle & \cdots \\
\langle \phi_{n+1} | H | \phi_m \rangle & \langle \phi_{n+1} | H | \phi_{m+1} \rangle & \cdots \\
\vdots & \vdots & \ddots & \vdots 
\end{pmatrix}
$$

$$
\langle \phi_i | \phi_n^\dagger \phi_m \phi_j \rangle = \langle 0 | \phi_i \phi_n^\dagger \phi_m \phi_j^\dagger | 0 \rangle = \delta_{in} \langle 0 | \phi_m \phi_j^\dagger | 0 \rangle = \delta_{in} \delta_{jm} := (e_{nm})_{ij}
$$
\[ i\hbar \partial_t \psi = \left( \begin{array}{cc} i\hbar \sigma_x \partial_x & mc^2 \\ mc^2 & -i\hbar \sigma_x \partial_x \end{array} \right) \psi \]

\[ \psi := \left( \begin{array}{c} \psi_n \\ \psi_{n+1} \end{array} \right), \quad \psi_n = \left( \begin{array}{c} u_n \\ v_n \end{array} \right) = \left( \begin{array}{c} u_n^1 \\ u_n^2 \\ v_n^1 \\ v_n^2 \end{array} \right) \]
SIMULATING QFT\textsubscript{1}

\textbf{Schrödinger equation}

\[ \partial_t \phi = i \frac{\hbar}{2m} \partial_x^2 \phi \]

\[ \omega = \frac{\hbar}{2ma^2} \]

\[ H = \sum_j e_{j+1,j} - 2e_{j,j} + e_{j,j+1} = \begin{pmatrix} \ldots & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\ \ldots & 1 & -2 & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \end{pmatrix} \]

\[ H = H^{(0)} + H^{(1)}, \quad H^{(0)} = \sum_j H_{2j,2j+1}, \quad H^{(1)} = \sum_j H_{2j+1,2j+2} \]

\[ H_{j,j+1} = \sum_j e_{j+1,j} - e_{j,j} - e_{j+1,j+1} + e_{j,j+1} \]
“Trotterize” the Hamiltonian

\[ H = H^{(0)} + H^{(1)}, \quad H^{(0)} = \sum_j H_{2j, 2j+1}, \quad H^{(1)} = \sum_j H_{2j+1, 2j+2} \]

\[ H_{j, j+1} = \sum_j e_{j+1, j} - e_{j, j} - e_{j+1, j+1} + e_{j, j+1} \]

By taking the maximal causal speed equal to \( C \) namely \( a \propto N^{-1} \) one obtains:

\[ \omega = \frac{\hbar}{2ma^2} \propto N^2 \]

The Schrödinger equation is not Lorentz invariant!
The Dirac Quantum Field Simulator.

In the second quantization the Dirac field becomes an operator obeying the following equal-time anticommutation relations

\[ \psi(x) \psi(y) = \psi(y) \psi(x) + \delta_{xy} \]

or

\[ \psi(x) \psi(y) = \psi(y) \psi(x) - \delta_{xy} \]

where \( \delta_{xy} \) is the Kronecker delta function.

The Hamiltonian of the Dirac field is given by

\[ H = \sum_{x} \left( \bar{\psi}(x) \gamma^0 \psi(x) - \sum_{\alpha} m \bar{\psi}(x) \gamma^\alpha \psi(x) \right) \]

where \( \gamma^0, \gamma^\alpha \) are the Dirac matrices.

Gauge invariance

In the context of QCD, the gauge symmetry is

\[ U(x) \psi(x) = e^{i \phi(x)} \psi(x) \]

\[ \psi(x) U(x) = e^{-i \phi(x)} \psi(x) \]

The choice of \( U(x) \) and \( e^{i \phi(x)} \) depends on the specific gauge group, which can be non-abelian or abelian.

QCFT

Gauge Invariance

Non-Abelian

\[ U(x) \]

Abelian

\[ e^{i \phi(x)} \]
SIMULATING QFT
GAUGE INVARIANCE

\[ \psi_n(t + \tau) = \psi_n(t) - i\varepsilon H \psi_n(t), \quad \varepsilon = \frac{c}{\upsilon}, \quad \upsilon = \frac{a}{\tau}. \]

\[ \psi_n = \begin{pmatrix} \psi_n^1 & \psi_n^2 & \cdots \end{pmatrix}, \quad \psi_n^j = \begin{pmatrix} u_n^j & v_n^j \end{pmatrix}. \]

\[ H = \begin{pmatrix} ... & 0 & 0 \end{pmatrix}, \quad H = \begin{pmatrix} 0 & -i2\sigma_x & \cdots \end{pmatrix}. \]

\[ \lambda = \frac{\bar{h} m c}{3.86159 \times 10^{-13}} \text{ is the reduced Compton wavelength.} \]

Gauge invariance
\[ U(x)e^{i\phi(x)} \]

The Dirac Quantum Simulator
\[ \psi(x) = \begin{pmatrix} \gamma(x) \end{pmatrix}, \quad \psi^\dagger(x) = \begin{pmatrix} \gamma^\dagger(x) \end{pmatrix}. \]

\[ \{ \psi(x), \psi^\dagger(y) \} = \delta(x - y), \quad \{ \psi(x), \psi(y) \} = 0. \]

\[ \sigma_z \psi_n \sigma^\dagger_n = \begin{pmatrix} -\psi_n \end{pmatrix}, \quad \psi_n = \begin{pmatrix} \psi_n \end{pmatrix}. \]

Good for Gravity!
Natively nonabelian Gauge theory!
and on ... foliation !!!
PLAY GOD WITH QCFT
or else: Einstein demystified
GR from QT?

positive and negative masses
GR from QT?

a worm hole!
GR from QT?

a black hole!
GR from QT?
a time tunnel!
GR from QT?
Advantages of QCFT versus QFT

QFT PROBLEMS
- Nonstandard representation of Feynman path integral (Nakamura)
- Action at distance or at contact
- Logical problems
- Other mathematical problems
- Feynman's path integral
- Problems from continuum
- Infinities (renormalization of UV divergencies)
- Operationally defined
- Causal network
- Lattice theory

QCFT SOLUTIONS
- Problems with localization
- Causality leakage
- Local observables
- Grassman variables
- Operationally meaningless
- PB quantization and $\Lambda$
- Action at distance or at contact

Logical problems
- PB quantization and $\Lambda$
- Operationally meaningless
- Grassman variables
Moreover, you can change the computational engine from QT to super-QT, or even non-causal OpT, without changing the theoretical framework.
THE PRINCIPLE OF THE QUANTUMNESS

Convex theories

Theories with purification*

Operational theories

Theories with local discriminability

Causal theories

CM

re-bit\textsubscript{2}

PR-boxes

Combs

re-bit\textsubscript{1}

noncausal theories

QT
“Emergent” Physics

* Relativity
* Gravity
* Field Theory
* Quantization rules and $\hbar$
* ...
TODO list

* Improve Ichonise and Tamura bound
* Derive Lorentz covariance of field
* Dirac and e.m. field in 3d
* Connect Lagrangian density with a circuit tile
* Derive a 1dim toy (non)abelian gauge theory
* Re-examine microcausality:
  * Fermi, Bose, para-statistics?
* Rederive quantization rules
* Re-derive Feynman path integral via Trotter
* Explore connections with lattice theories
* Rederive GR Einstein’s equation
* Explore Penrose spin-networks, Regge calculus, etc.
* Rederive gauge theories
* Write a Theory of...
  * Quantum Gravity!
Concluding remarks

- QCFT seems to have many advantages versus QFT
- It puts the nose on the foundational problems in QFT
- It is QG-ready
- It’s fun! (a good excuse to study more physics)
- It brings Quantum Information to particle physics, GR, and cosmology!