Robert Harlander

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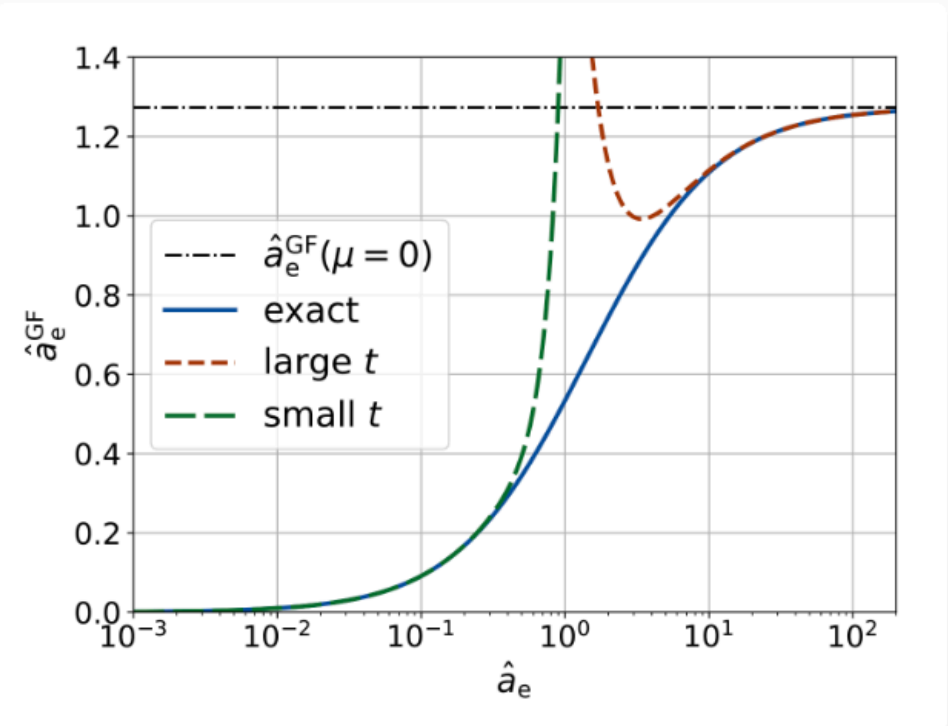
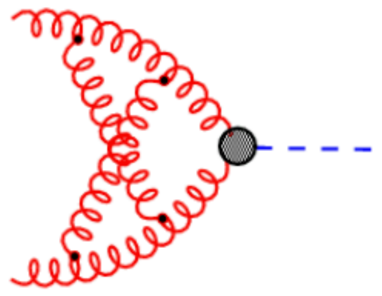


What's new? (older news)

- Topics for bachelor theses
  22 Jan 2026
- New preprint on the gradient-flow coupling in QED
  21 Jan 2026
- New podcast episode: Schwere Quarks mit Sieg(en)er-Gen
  07 Jan 2026
- New preprint on quark-mass effects in gradient-flow observables
  23 Dec 2025



One of my favorite Feynman diagrams

I am a professor for theoretical particle physics at RWTH Aachen University.

My main research field is to understand and predict phenomena at particle colliders. Within the last few years, I have been mostly interested in the physics of Higgs bosons in and beyond the Standard Model. Recently, I have also become interested in improving the connection between the perturbative and the lattice approach to quantum field theory through the gradient-flow formalism.

The menu on the left should help you navigate through this page. In particular, you can find a Brief CV, and details about my Research and Teaching activities.

It is important to try to convey some of our excitement about physics to the general public, high-school students, or politicians. As you can see in the Outreach section of this page, I have been quite active in this field. If you are interested in organizing an outreach activity (public lecture, information for high-school students etc.), feel free to contact me.

Most of the time, you will know where I am by clicking the Conferences item.

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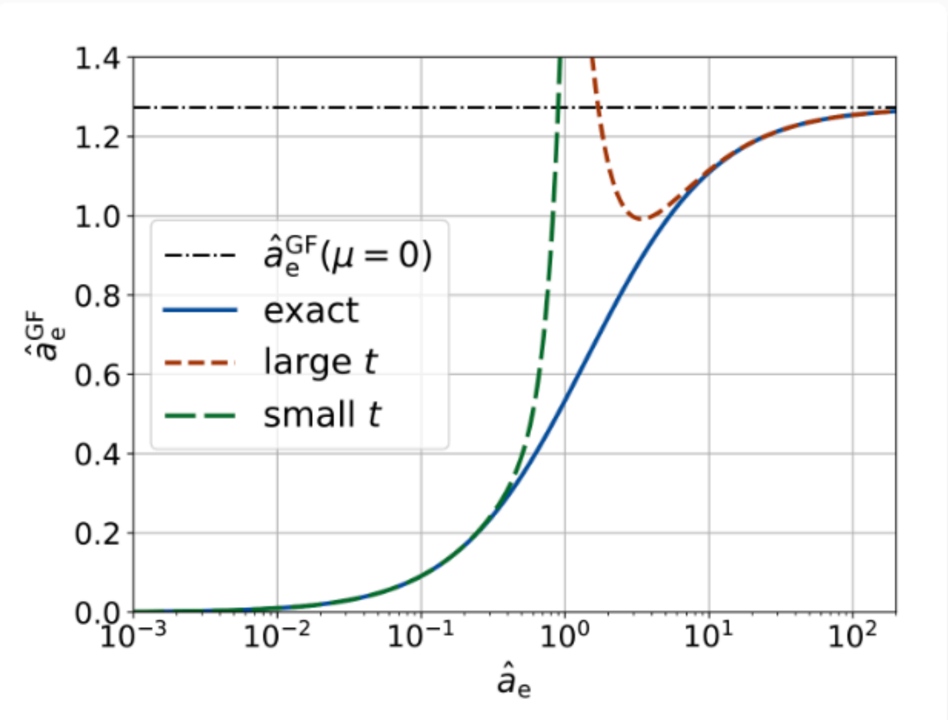

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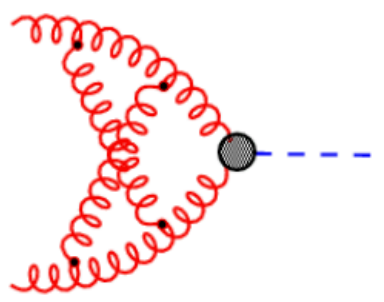

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Bachelor Topics for summer term 2026

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▸ **The flavor structure of Effective Field Theories**

▸ **Effective Field Theories and Birdtrack diagrams**

▸ **Consistency relations in the gradient-flow formalism**

▸ **Understanding Feynman diagrams in a playful way**

last updated on Jan 19, 2026 by RH

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▾ The flavor structure of Effective Field Theories

What determines the hierarchy of the particle masses? Is there an underlying mechanism that relates the flavor and the mass eigenstates of the fermions? These and similar questions on the **flavor structure** are left completely unanswered by the Standard Model.

If there is an explanation for this structure, it should be reflected in higher-dimensional operators of **effective field theories**. The software tool **AutoEFT** provides the basis for exploring such structure on a systematic level with the help of so-called **spurions**.

In this project, you are going to study the concept of spurions which allows one to impose a certain flavor symmetry on the effective field theory. Given a certain set of spurions, you are going to construct invariants under this flavor symmetry, ensuring the absence of redundant structures.

You will learn the physical and mathematical concepts of Effective Field Theories and the associated theoretical tools like group theory and representations.

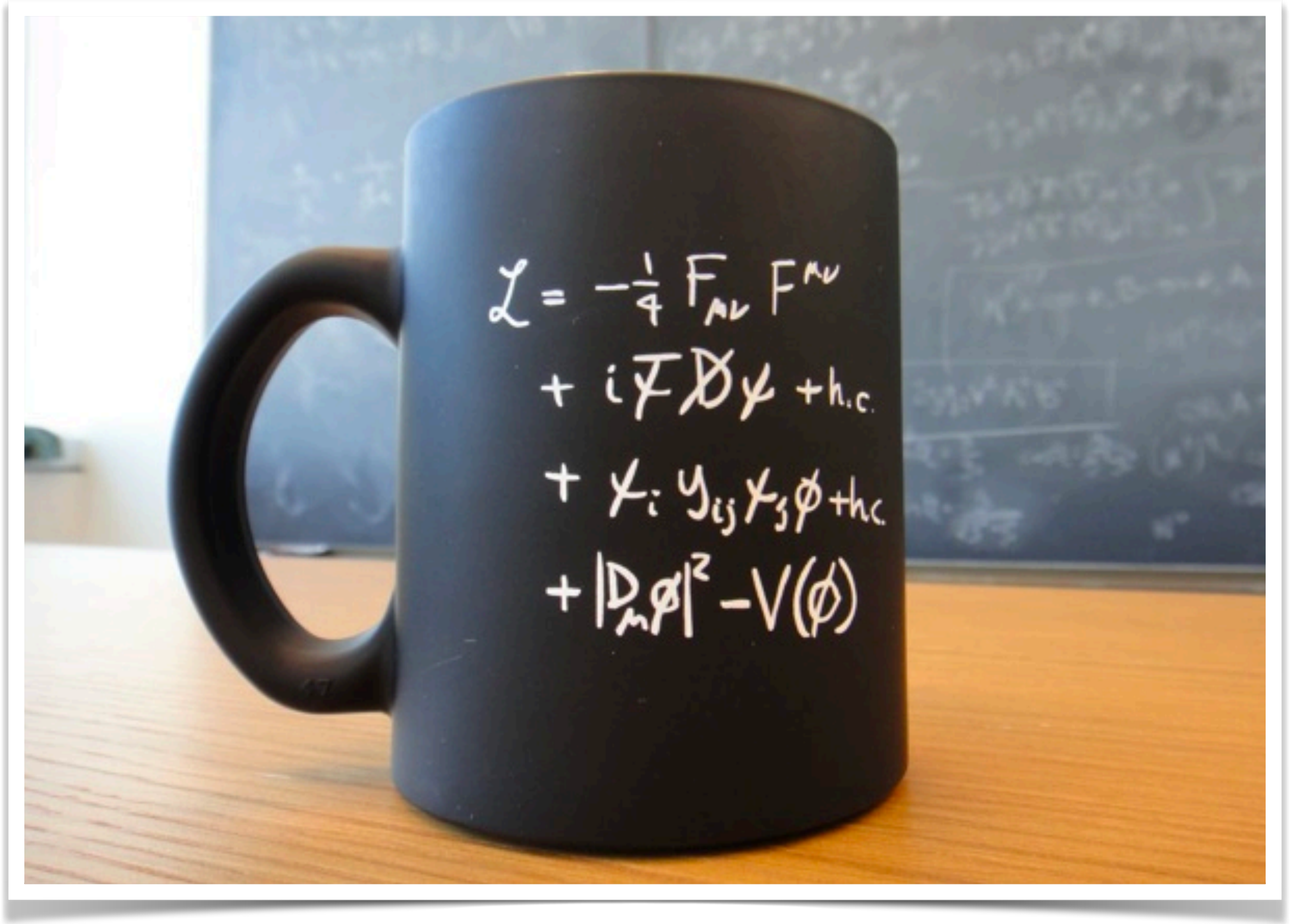
▸ Effective Field Theories and Birdtrack diagrams

▸ Consistency relations in the gradient-flow formalism

▸ Understanding Feynman diagrams in a playful way

Flavor structures in Effective Field Theories

Standard Model:



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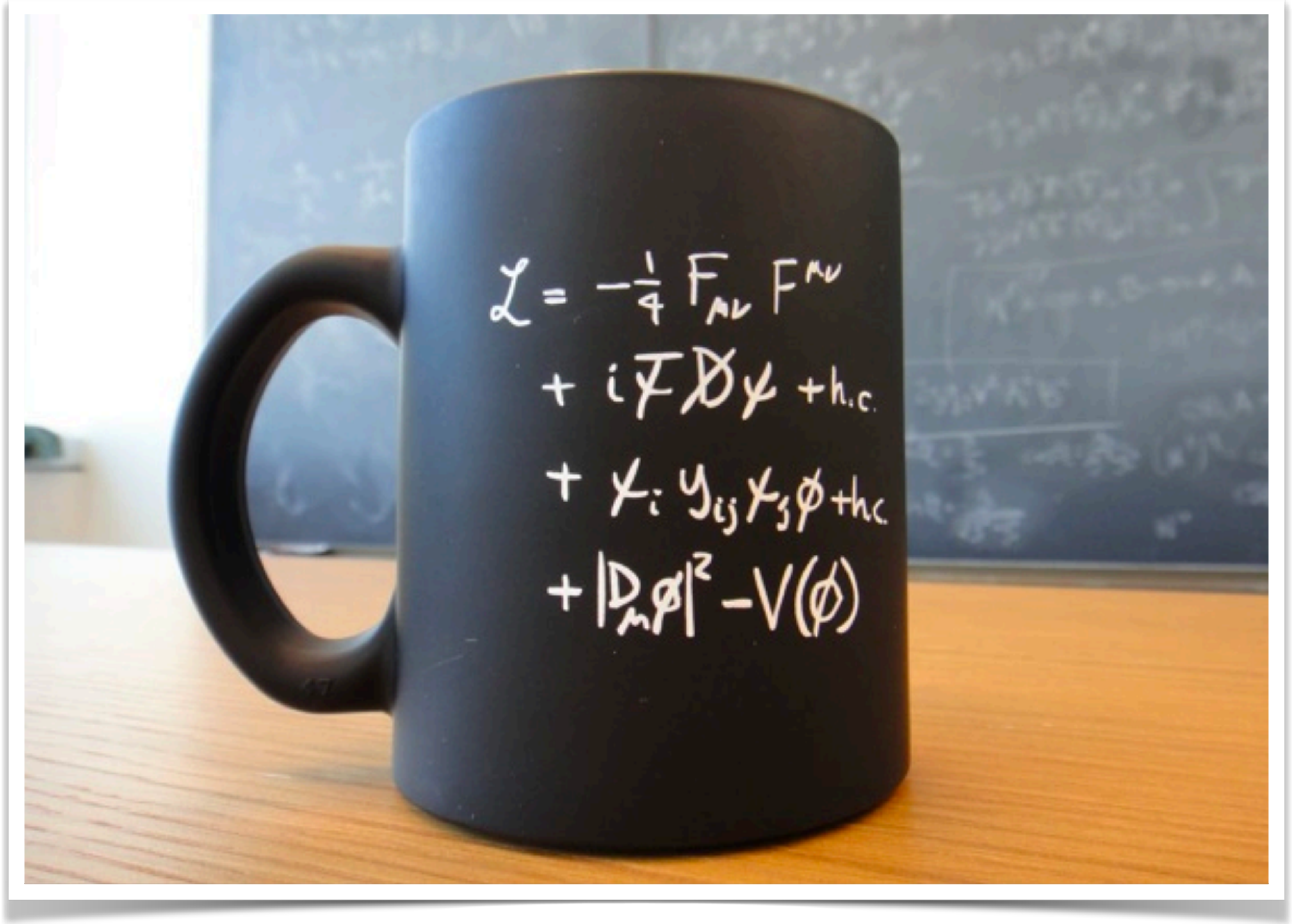

18 parameters

Flavor structures in Effective Field Theories

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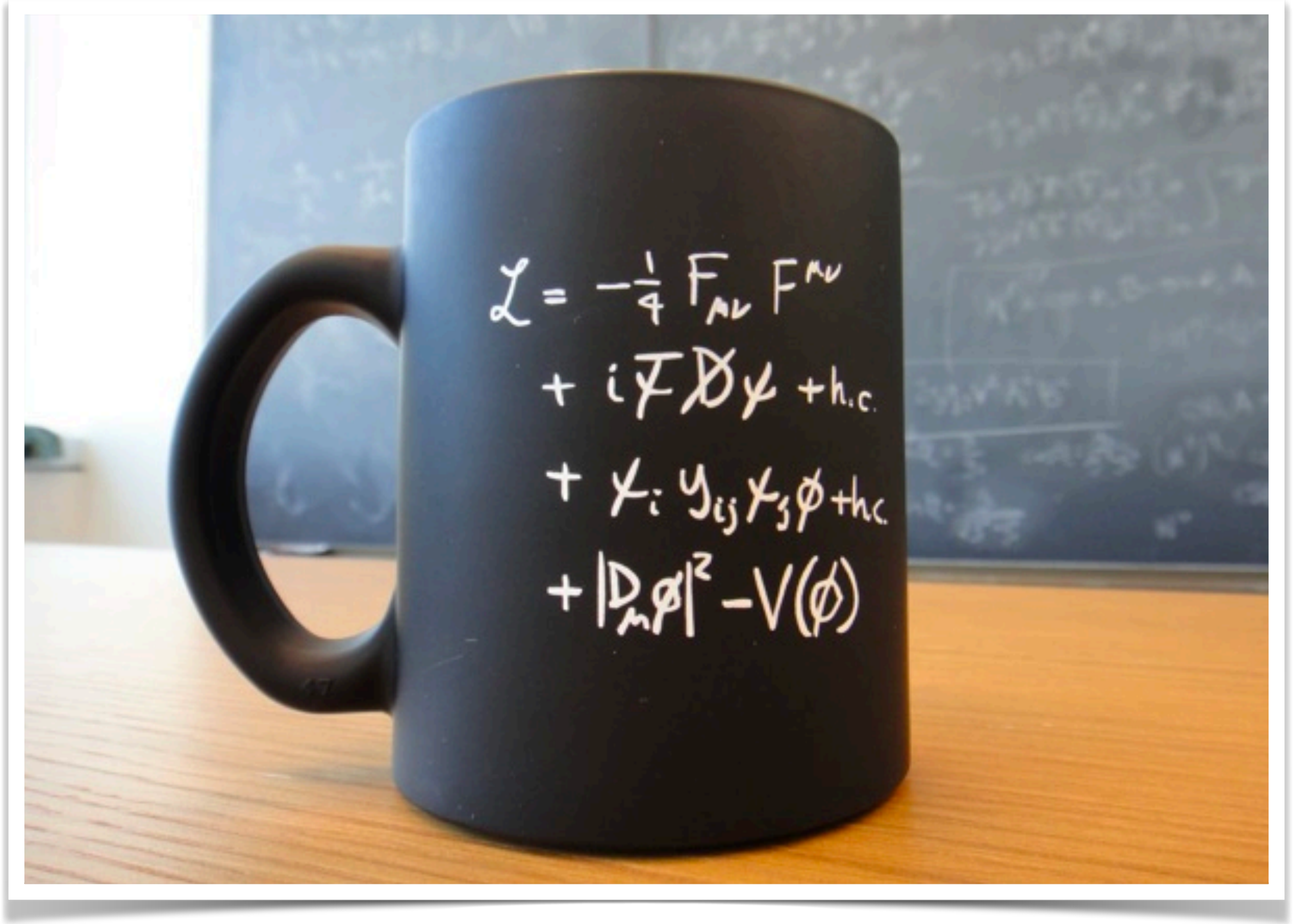
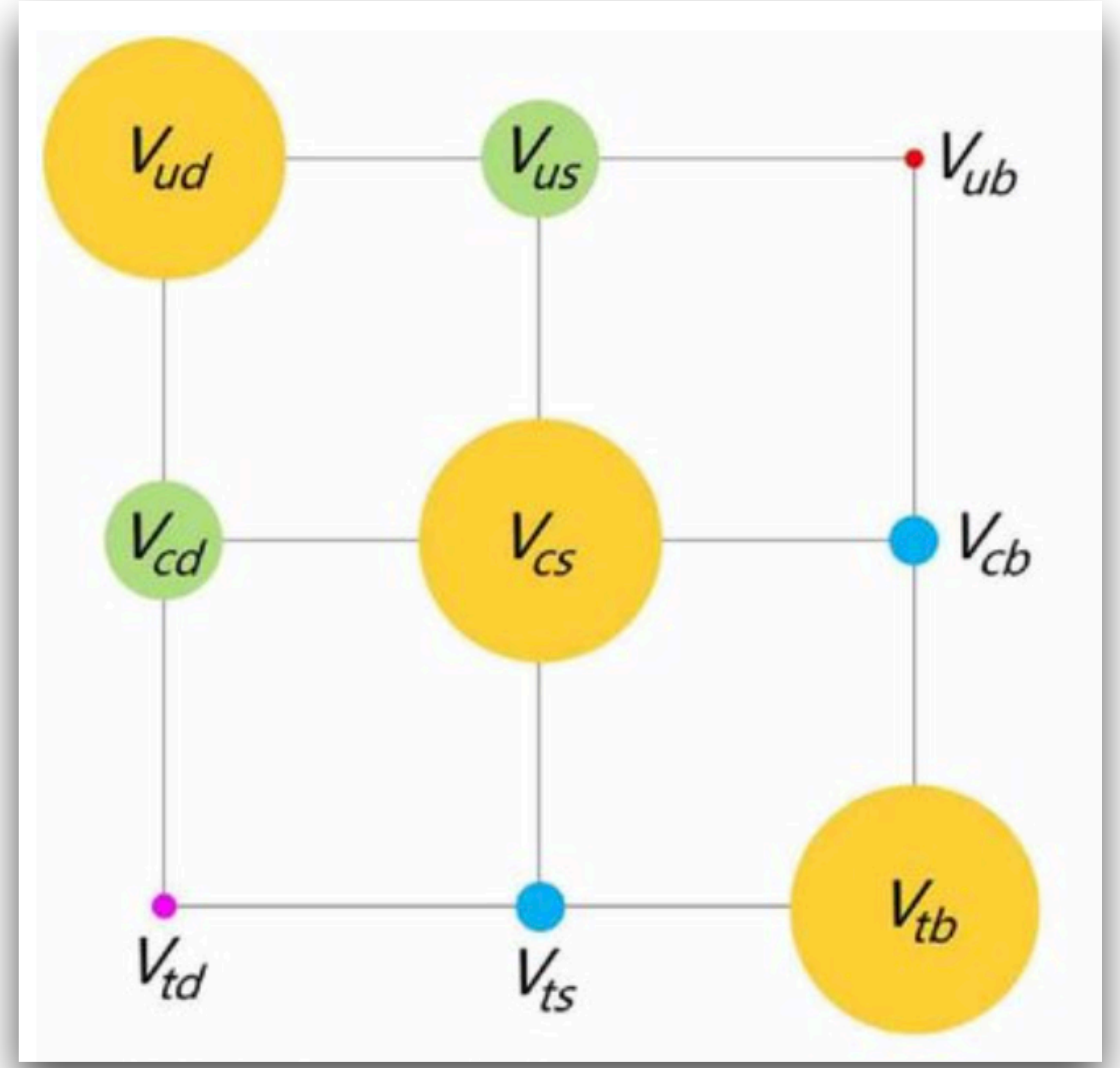


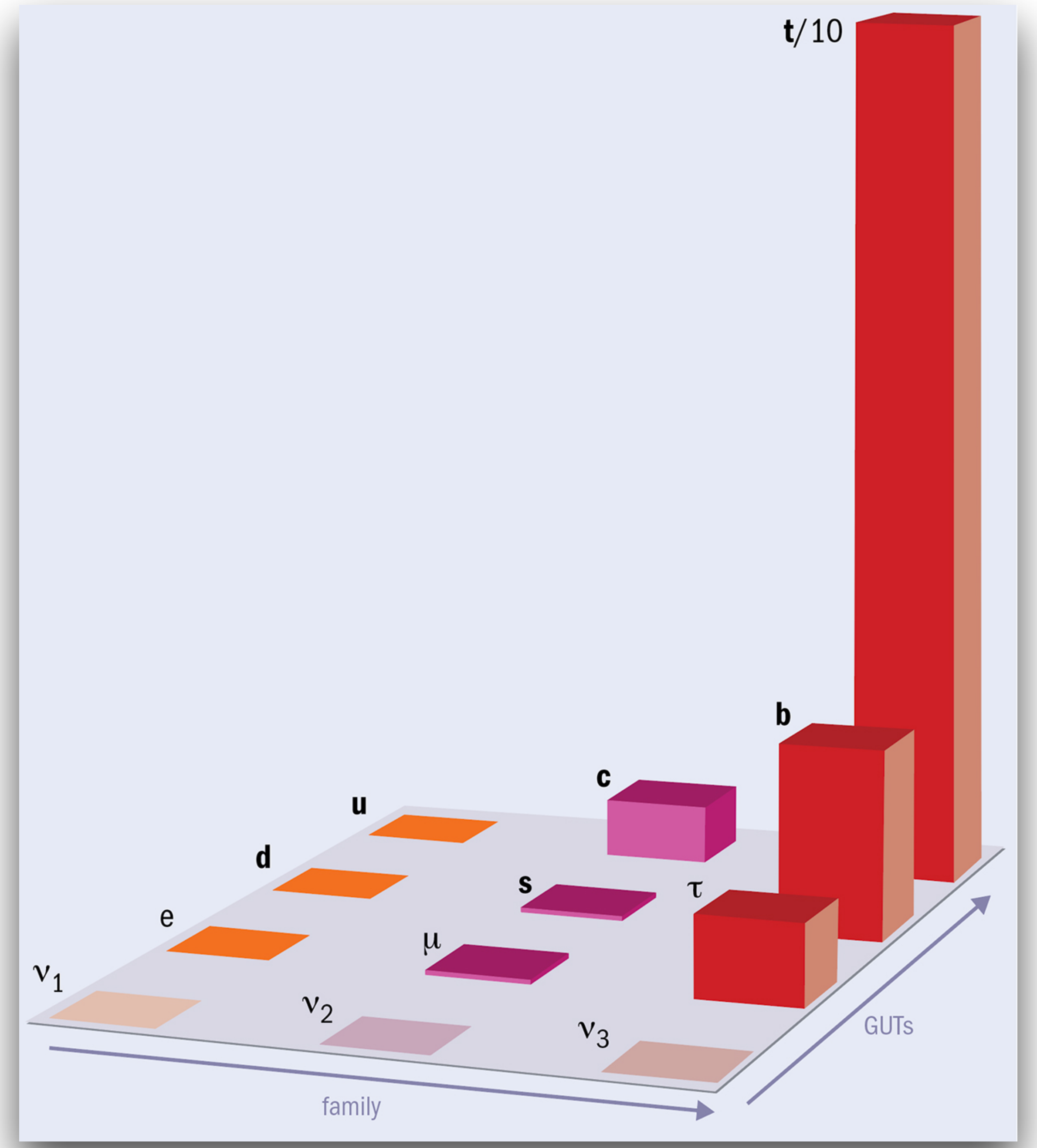
18 parameters

13 related to flavor!

Effective Field Theories: Flavor Structures

Flavor hierarchies:





Reflected in SMEFT parameters? Minimal Flavor Violation? Froggatt-Nielsen?

Flavor structures in Effective Field Theories

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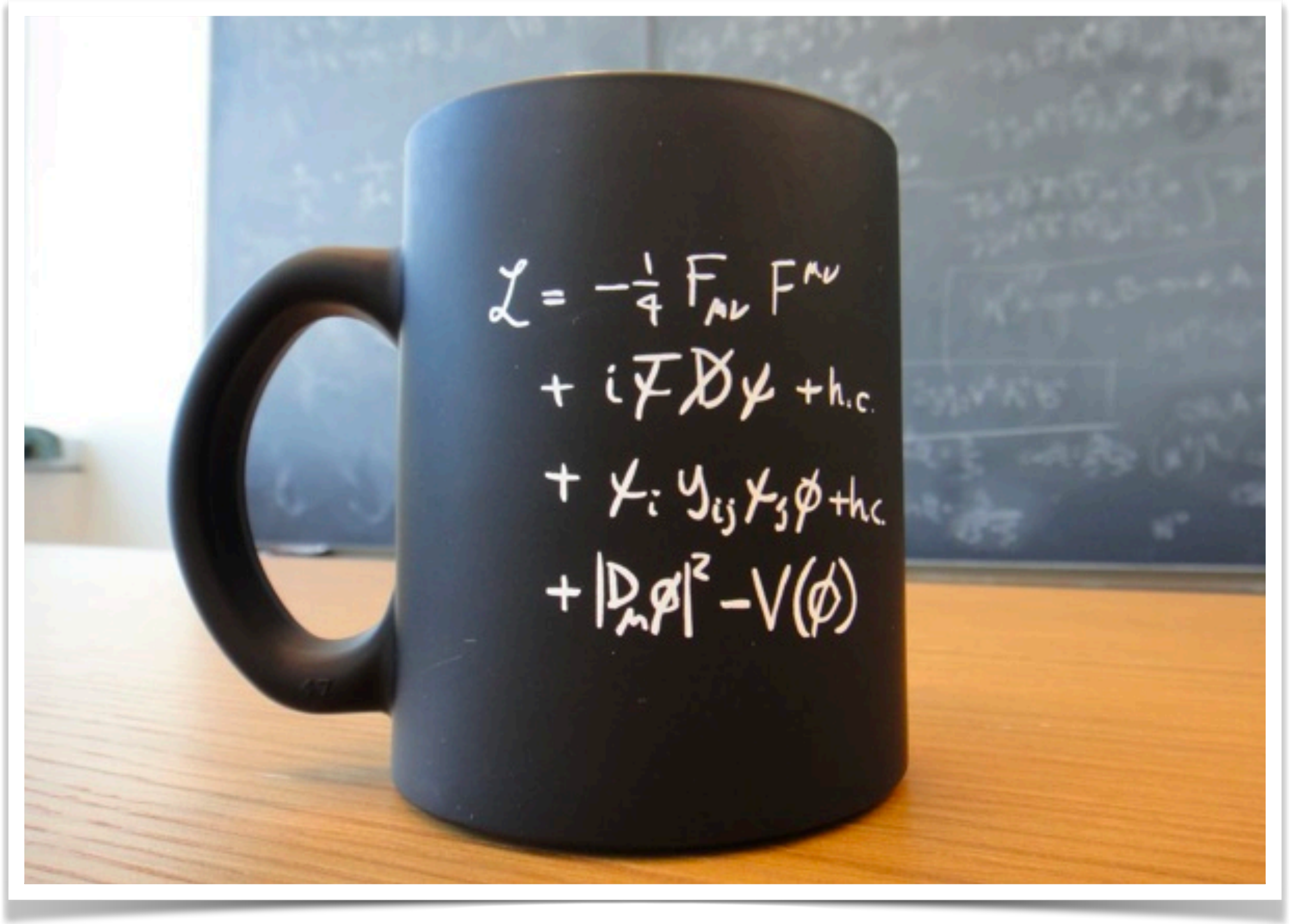

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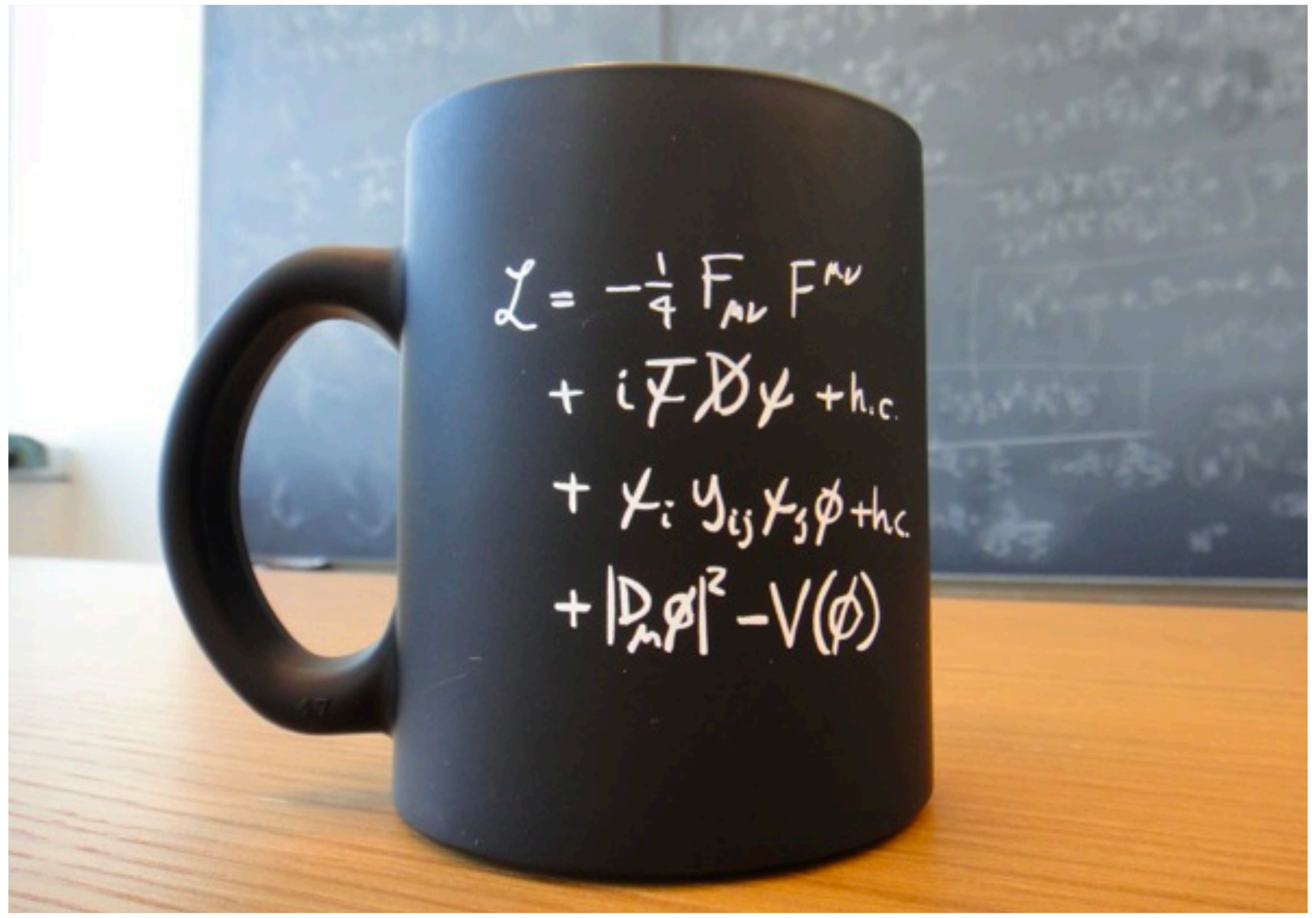

18 parameters

13 related to flavor!

SMEFT

$1: X^3$		$2: H^6$		$3: H^4D^2$		$5: \psi^2H^3 + \text{h.c.}$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_H	$(H^\dagger H)^3$	$Q_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	Q_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$			Q_{HD}	$\left(H^\dagger D_\mu H\right)^* \left(H^\dagger D_\mu H\right)$	Q_{uH}	$(H^\dagger H)(\bar{q}_p u_r \widetilde{H})$
Q_W	$\epsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$					Q_{dH}	$(H^\dagger H)(\bar{q}_p d_r H)$
$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$						

$8: (\bar{L}R)(\bar{R}L) + \text{h.c.}$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$

$8: (\bar{L}R)(\bar{L}R) + \text{h.c.}$	
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\epsilon_{jk}(\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\epsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r)\epsilon_{jk}(\bar{q}_s^k \sigma^{\mu\nu} u_t)$

$4: X^2H^2$		$6: \psi^2XH + \text{h.c.}$		$7: \psi^2H^2D$	
Q_{HG}	$H^\dagger H\, G_{\mu\nu}^A G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p \sigma^{\mu\nu} e_r)\tau^I H W_{\mu\nu}^I$	$Q_{Hl}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p \gamma^\mu l_r)$
$Q_{H\widetilde{G}}$	$H^\dagger H\, \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$	$Q_{Hl}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^I H)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{HW}	$H^\dagger H\, W_{\mu\nu}^I W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p \sigma^{\mu\nu} T^A u_r)\widetilde{H}\, G_{\mu\nu}^A$	Q_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p \gamma^\mu e_r)$
$Q_{H\widetilde{W}}$	$H^\dagger H\, \widetilde{W}_{\mu\nu}^I W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\tau^I \widetilde{H}\, W_{\mu\nu}^I$	$Q_{Hq}^{(1)}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p \gamma^\mu q_r)$
Q_{HB}	$H^\dagger H\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p \sigma^{\mu\nu} u_r)\widetilde{H}\, B_{\mu\nu}$	$Q_{Hq}^{(3)}$	$(H^\dagger i\overleftrightarrow{D}_\mu^I H)(\bar{q}_p \tau^I \gamma^\mu q_r)$
$Q_{H\widetilde{B}}$	$H^\dagger H\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p \sigma^{\mu\nu} T^A d_r) H\, G_{\mu\nu}^A$	Q_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p \gamma^\mu u_r)$
Q_{HWB}	$H^\dagger \tau^I H\, W_{\mu\nu}^I B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p \sigma^{\mu\nu} d_r)\tau^I H\, W_{\mu\nu}^I$	Q_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p \gamma^\mu d_r)$
$Q_{H\widetilde{W}B}$	$H^\dagger \tau^I H\, \widetilde{W}_{\mu\nu}^I B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p \sigma^{\mu\nu} d_r) H\, B_{\mu\nu}$	Q_{Hud} + h.c.	$i(\widetilde{H}^\dagger D_\mu H)(\bar{u}_p \gamma^\mu d_r)$

$8: (\bar{L}L)(\bar{L}L)$		$8: (\bar{R}R)(\bar{R}R)$		$8: (\bar{L}L)(\bar{R}R)$	
Q_{ll}	$(\bar{l}_p \gamma_\mu l_r)(\bar{l}_s \gamma^\mu l_t)$	Q_{ee}	$(\bar{e}_p \gamma_\mu e_r)(\bar{e}_s \gamma^\mu e_t)$	Q_{le}	$(\bar{l}_p \gamma_\mu l_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{uu}	$(\bar{u}_p \gamma_\mu u_r)(\bar{u}_s \gamma^\mu u_t)$	Q_{lu}	$(\bar{l}_p \gamma_\mu l_r)(\bar{u}_s \gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p \gamma_\mu \tau^I q_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar{d}_p \gamma_\mu d_r)(\bar{d}_s \gamma^\mu d_t)$	Q_{ld}	$(\bar{l}_p \gamma_\mu l_r)(\bar{d}_s \gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p \gamma_\mu l_r)(\bar{q}_s \gamma^\mu q_t)$	Q_{eu}	$(\bar{e}_p \gamma_\mu e_r)(\bar{u}_s \gamma^\mu u_t)$	Q_{qe}	$(\bar{q}_p \gamma_\mu q_r)(\bar{e}_s \gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p \gamma_\mu \tau^I l_r)(\bar{q}_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar{e}_p \gamma_\mu e_r)(\bar{d}_s \gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{u}_s \gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar{u}_p \gamma_\mu u_r)(\bar{d}_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar{q}_p \gamma_\mu T^A q_r)(\bar{u}_s \gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar{u}_p \gamma_\mu T^A u_r)(\bar{d}_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar{q}_p \gamma_\mu q_r)(\bar{d}_s \gamma^\mu d_t)$
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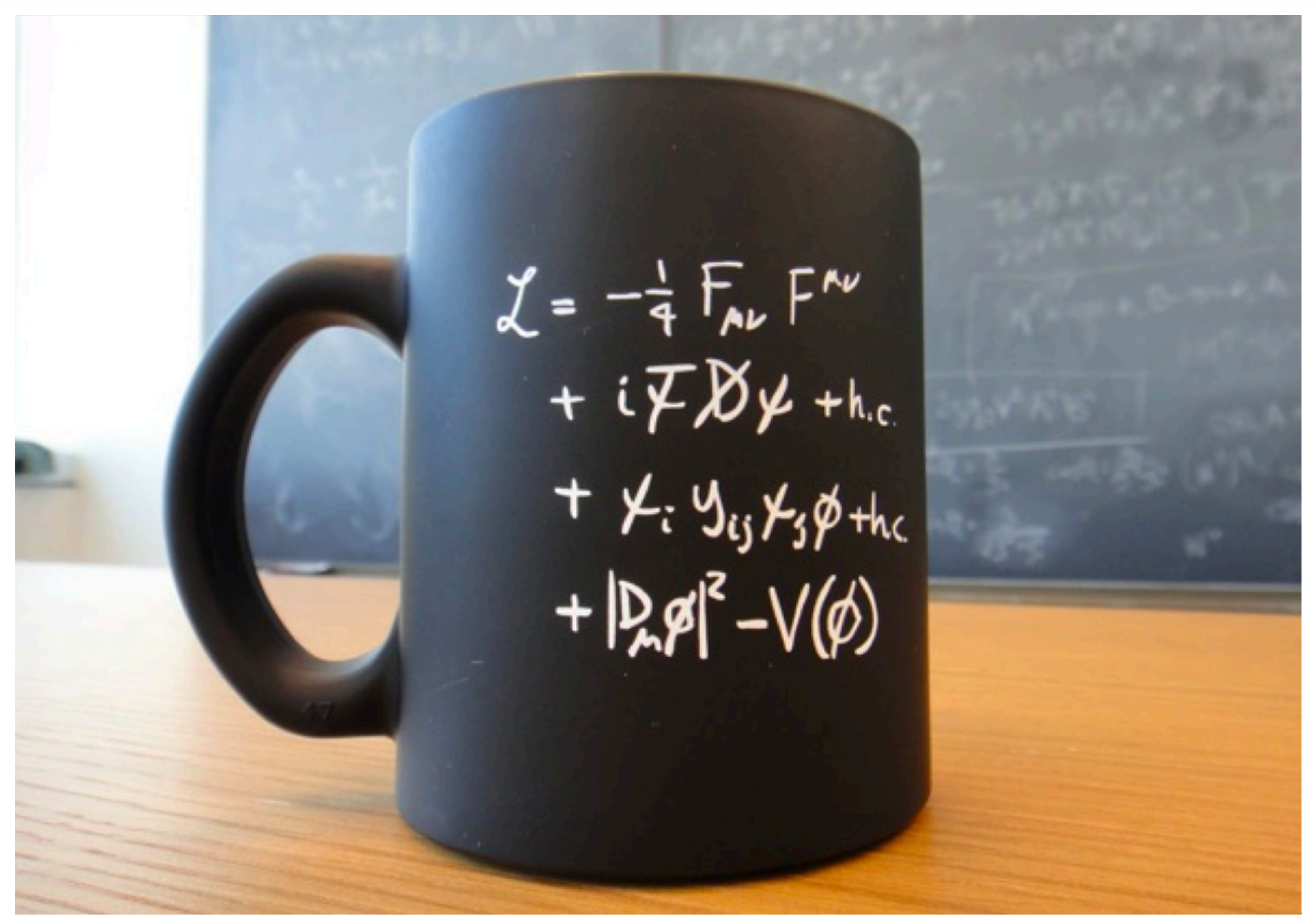
Flavor structures in Effective Field Theories

Standard Model:



18 parameters

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$Q_{\widetilde{W}}$	$\epsilon^{IJK} \widetilde{W}_\mu^{I\nu}$ [illegible]						

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2499 parameters

$4: X^2 H^2$					
Q_{HG}	$H^\dagger H$ [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$Q_{H\widetilde{G}}$	$H^\dagger H \widetilde{G}_{\mu\nu}^A G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p \sigma^{\mu\nu} e_r) H B_{\mu\nu}$	$Q_{Hl}^{(3)}$	$(H^\dagger i \overleftrightarrow{D}_\mu^I H)(\bar{l}_p \tau^I \gamma^\mu l_r)$
Q_{HW}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$Q_{H\widetilde{W}}$	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Q_{HB}	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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2452 related to flavor!

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▸ Consistency relations in the gradient-flow formalism

▸ Understanding Feynman diagrams in a playful way

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Bachelor Topics for summer term 2026

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To discuss in person, meet me in my office on Monday, **26 January 2026, at 11am**.

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▸ **The flavor structure of Effective Field Theories**

▾ **Effective Field Theories and Birdtrack diagrams**

Effective Field Theories (EFTs) describe physics beyond the Standard Model by including additional operators in the Lagrangian. **AutoEFT** is a program, developed within our group, that can construct independent sets of these **EFT operators**. The basis as well as the representation of the operators is not unique though, and **AutoEFT** currently makes a specific choice.

The goal of this thesis is to develop an algorithm that can translate EFT operators between different representations. One way to do this is to visualize the operators using **Birdtrack diagrams**. These diagrams make it much easier to understand the structure of the operators and to simplify them.

Finally, the algorithm should be implemented as a computer program.

You will learn:

- The basic concepts of Effective Field Theories
- How Birdtrack diagrams can be used to describe tensor contractions

▸ **Consistency relations in the gradient-flow formalism**

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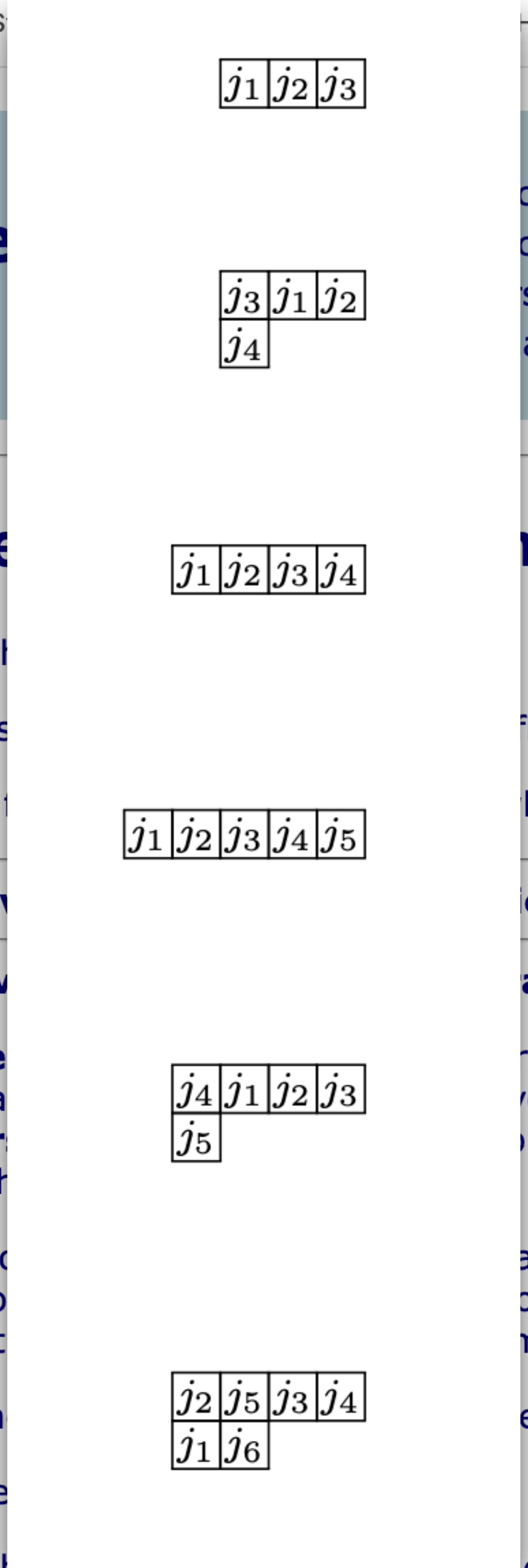

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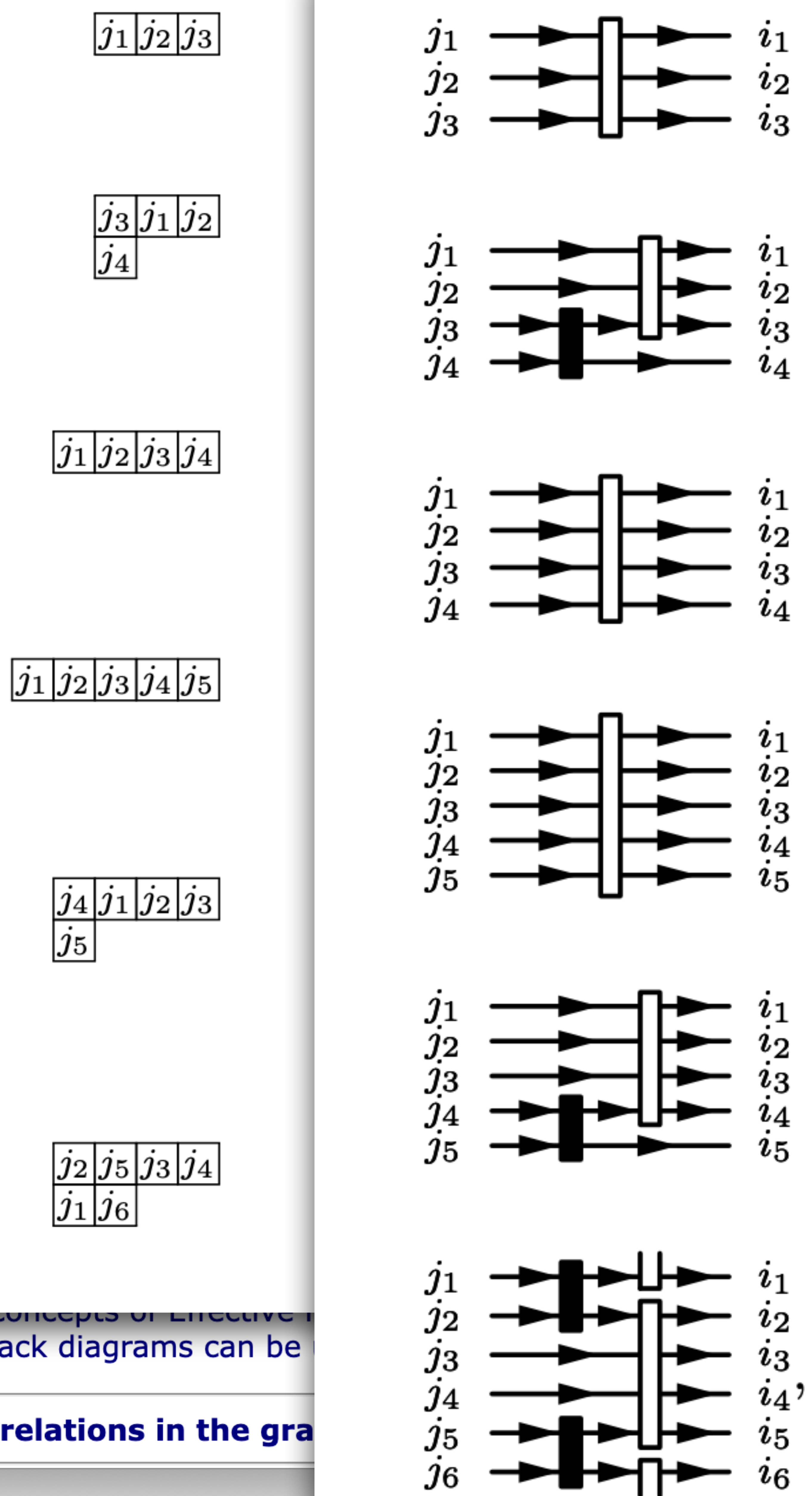

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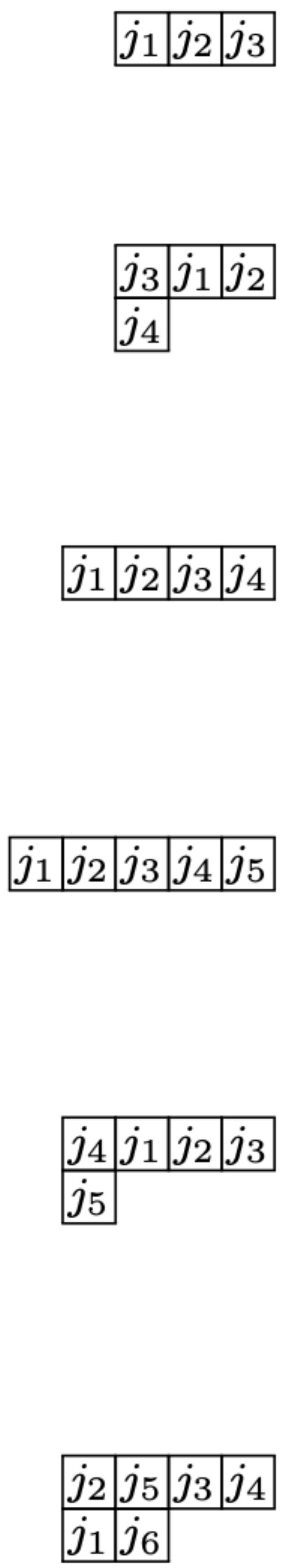

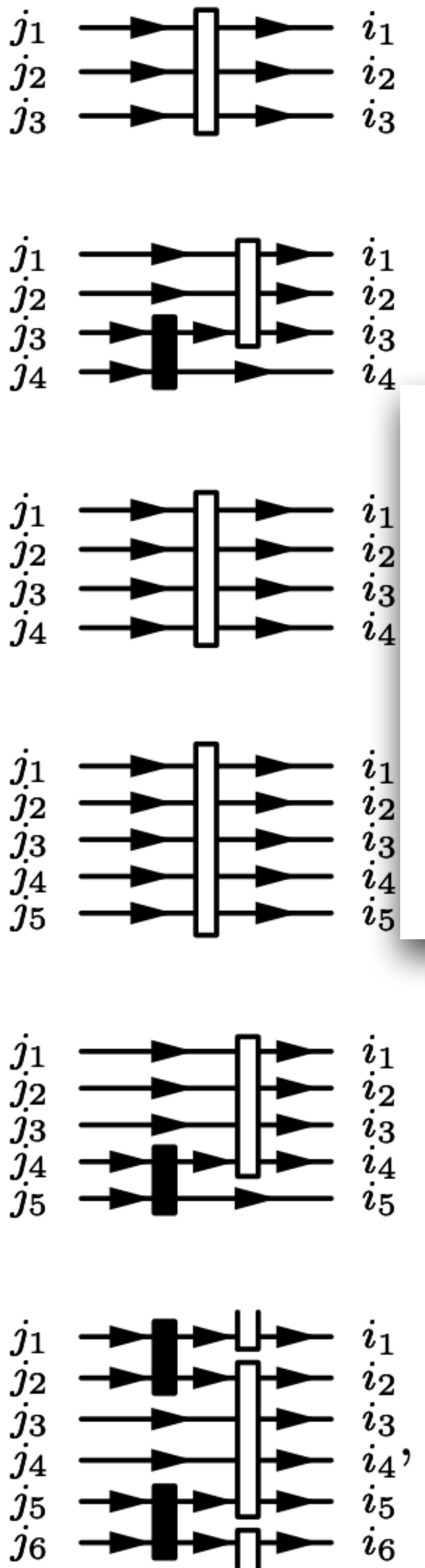

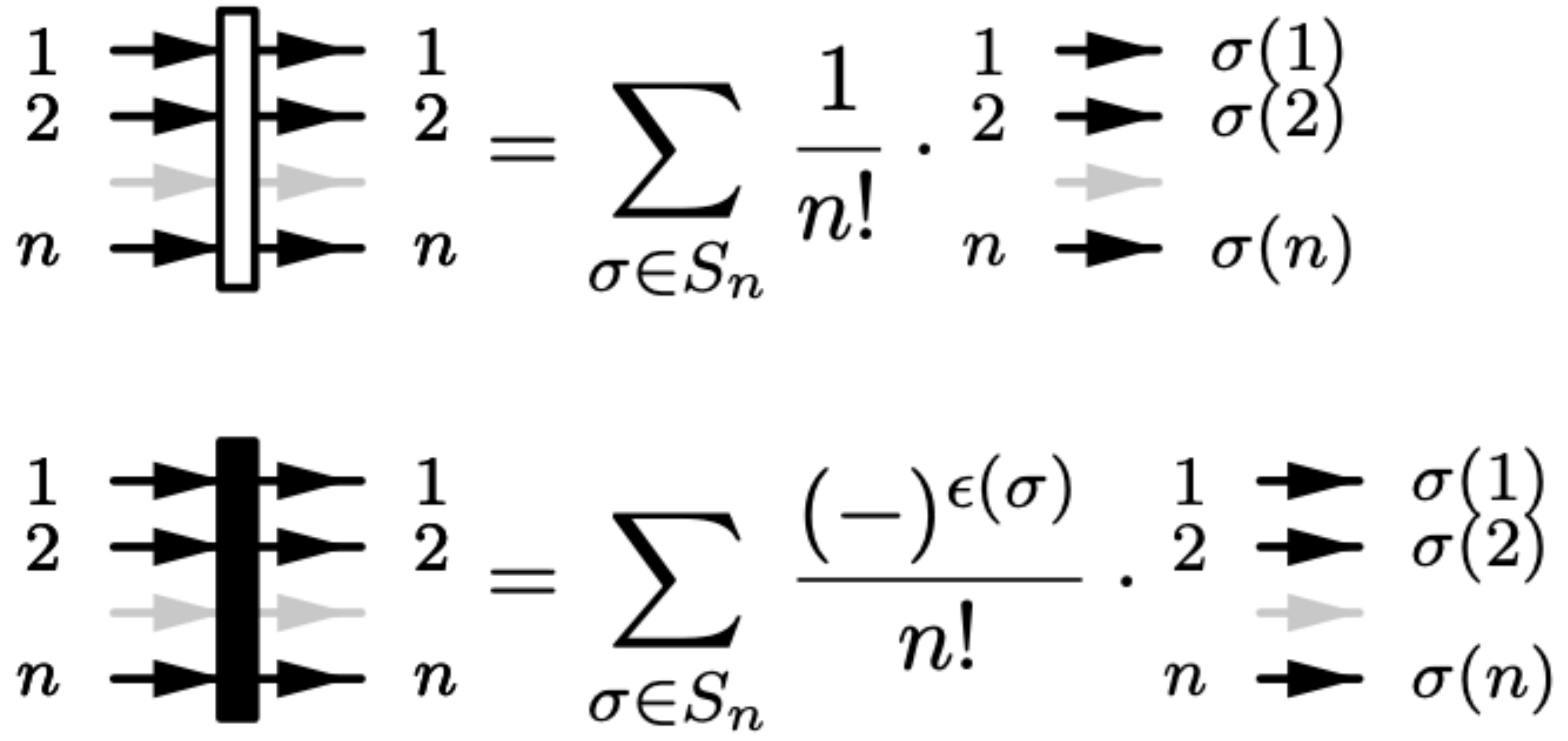

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last updated on Jan 19, 2026 by RH

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The **gradient-flow formalism** provides a way relate perturbative calculations to lattice calculations in QCD. The flow equations provide additional relations beyond the usual field equations on the flowed fields. They can be used to derive **non-trivial relations among observables**

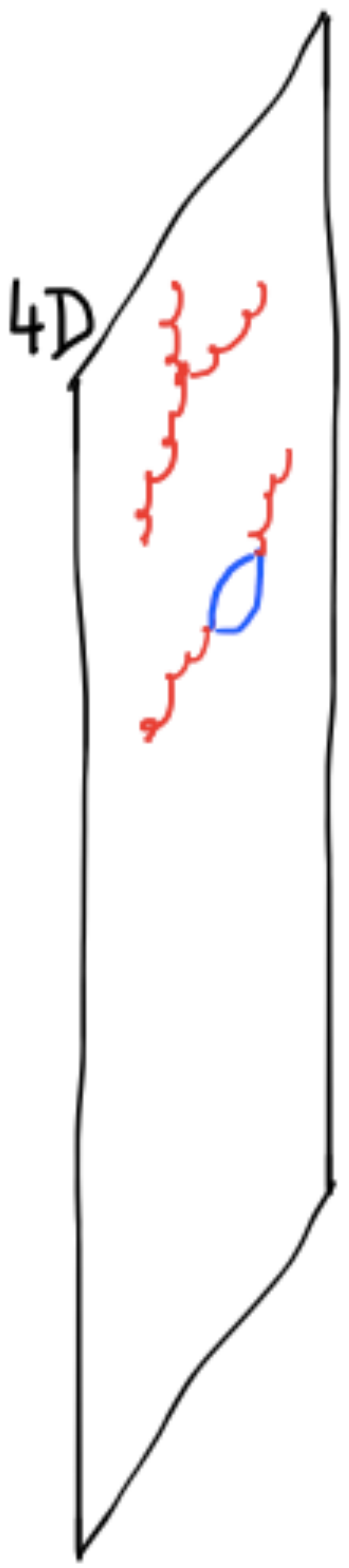
In this project, you will derive such relations for simple observables and verify them by doing explicit calculations.

You will learn:

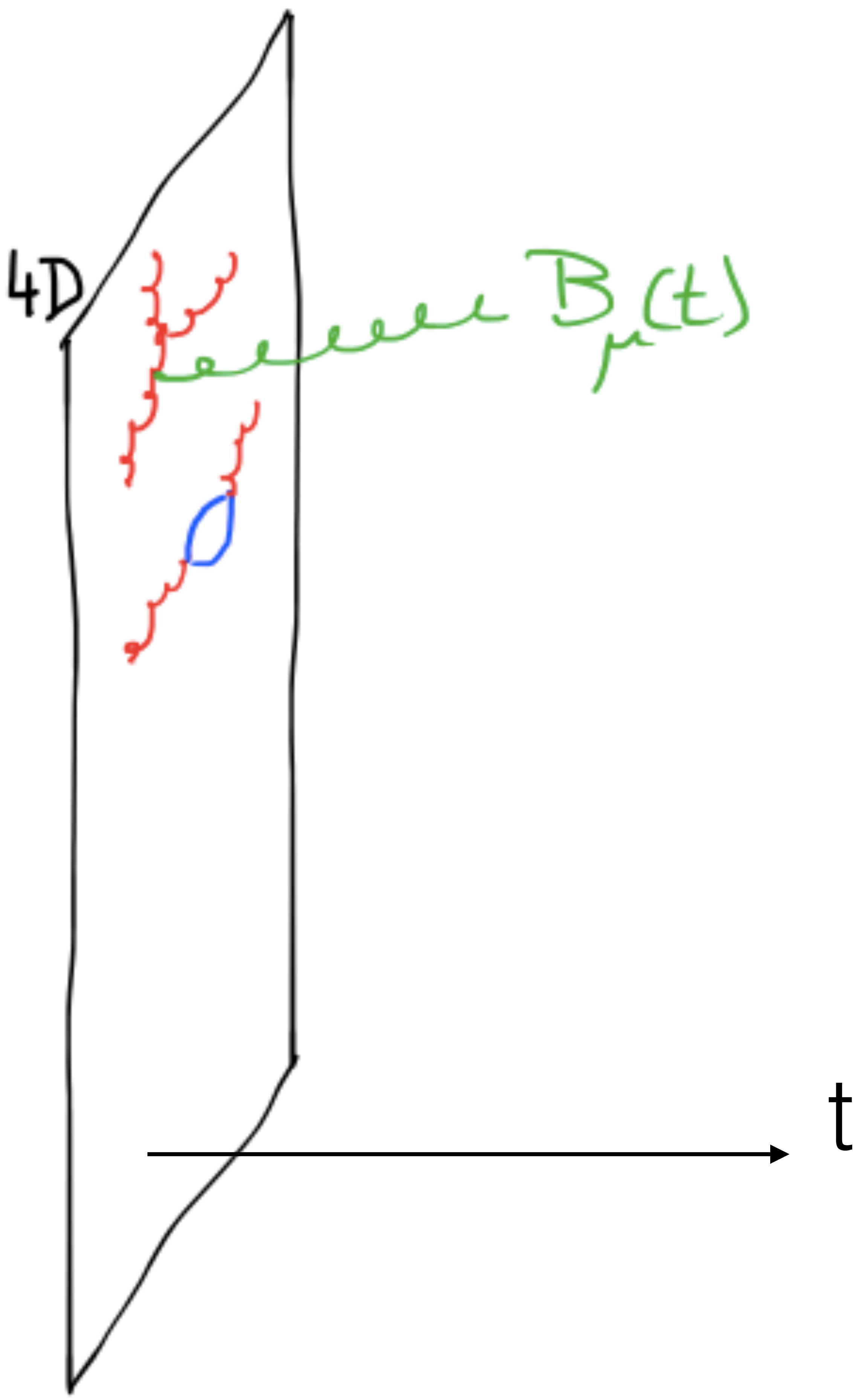
- The general method of the gradient flow.
- Approaches to calculating non-standard Feynman integrals.

▸ **Understanding Feynman diagrams in a playful way**

$$\mathscr{L} = \mathscr{L}_{\text{QCD}}$$



$$\mathscr{L} = \mathscr{L}_{\rm QCD} + \mathscr{L}_B$$



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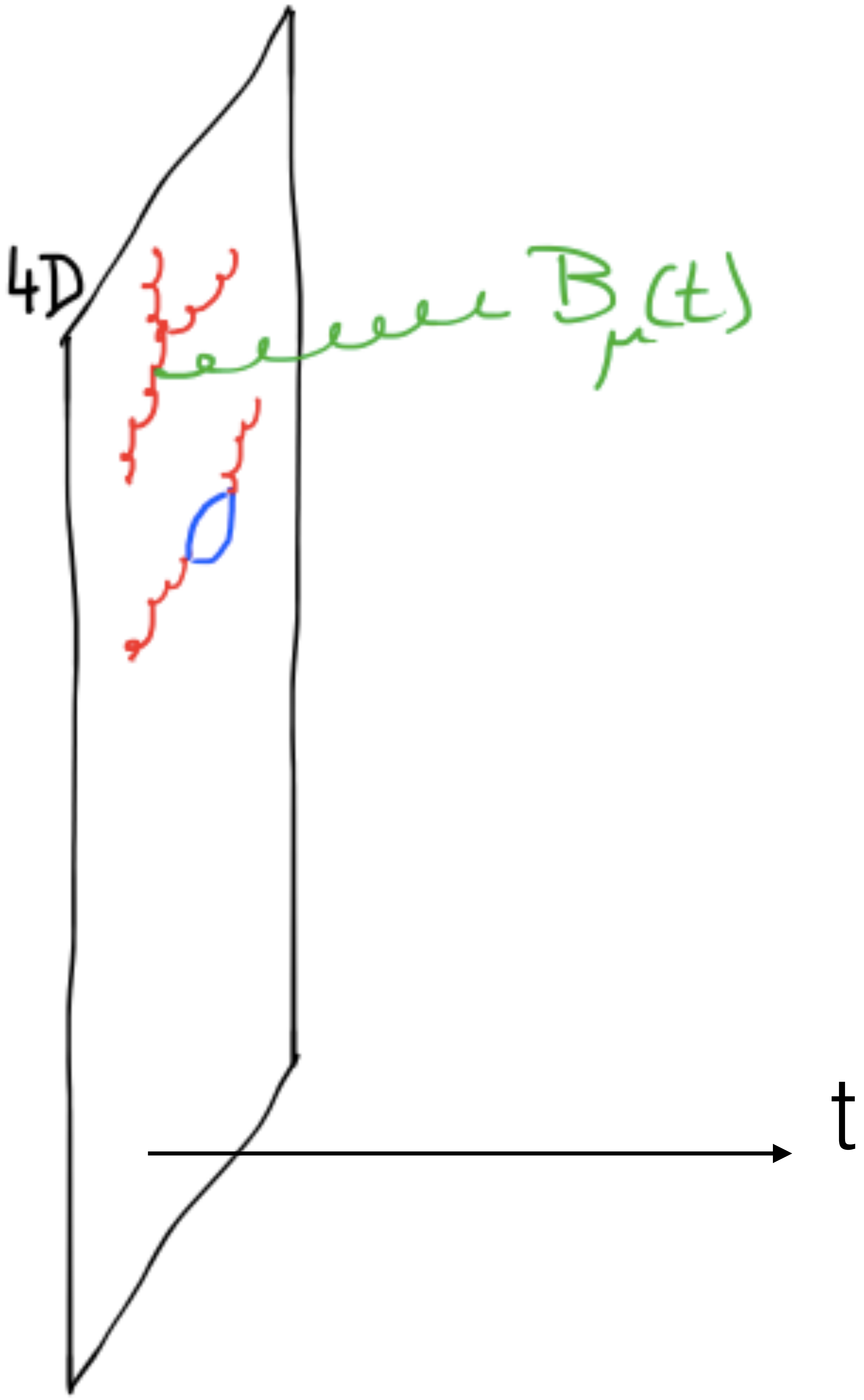

$$\partial_t \chi(t) = \Delta \chi(t)$$

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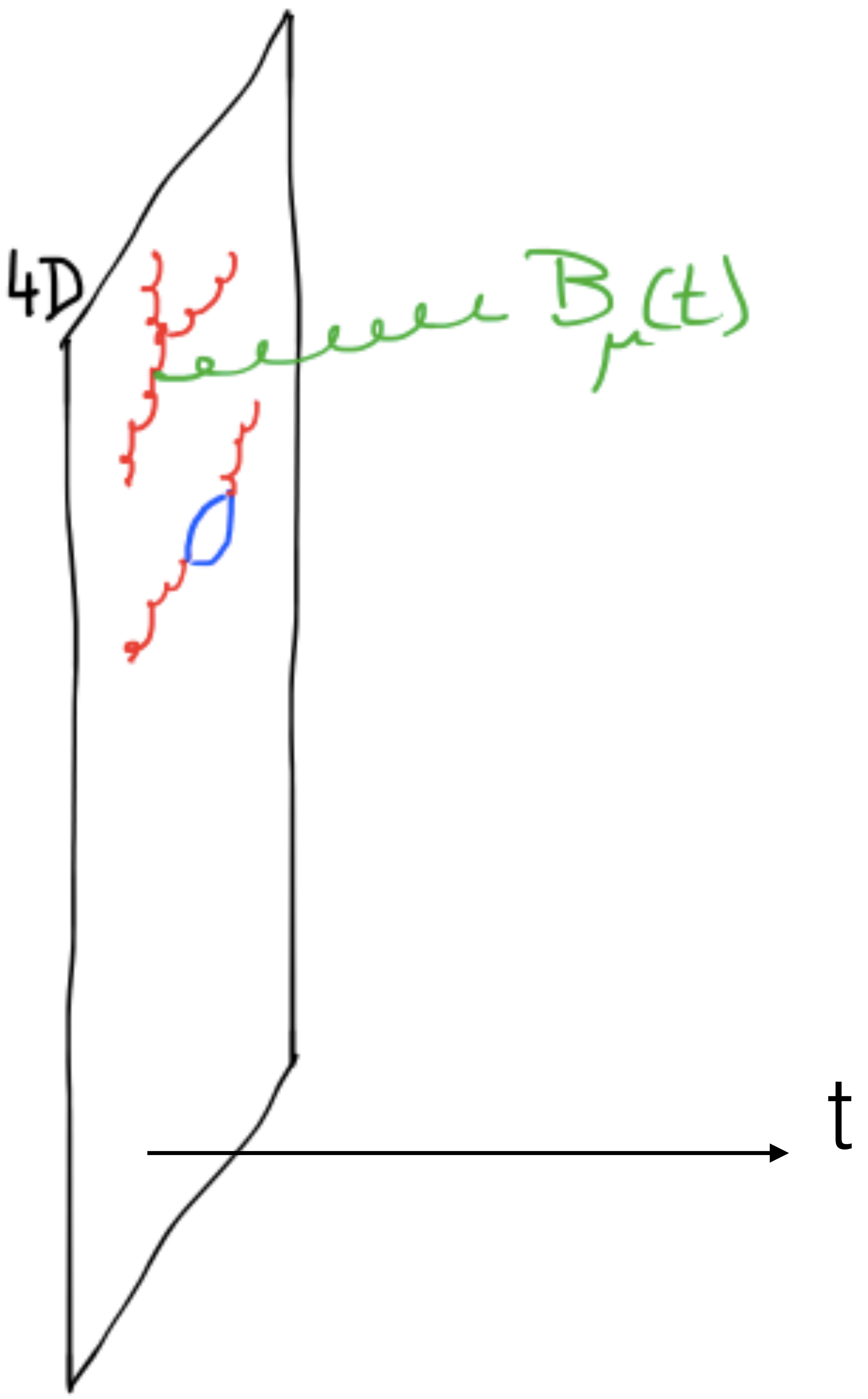

$$\partial_t \chi(t) = \Delta \chi(t)$$

$$\Rightarrow \quad \partial_t \langle \bar{\chi}\chi \rangle = \langle \bar{\chi} \overleftrightarrow{\Delta} \chi \rangle$$

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FeynGame is a tool to learn about the concept of **Feynman diagrams** in a playful way. It allows to easily produce high-quality images of Feynman diagrams. In this project, you will develop a new game to for FeynGame.

You will learn:

- The algorithmic structure of Feynman diagrams.

Requirements:

- Interest in Feynman diagrams.
- Possibly some affinity to computer programming.

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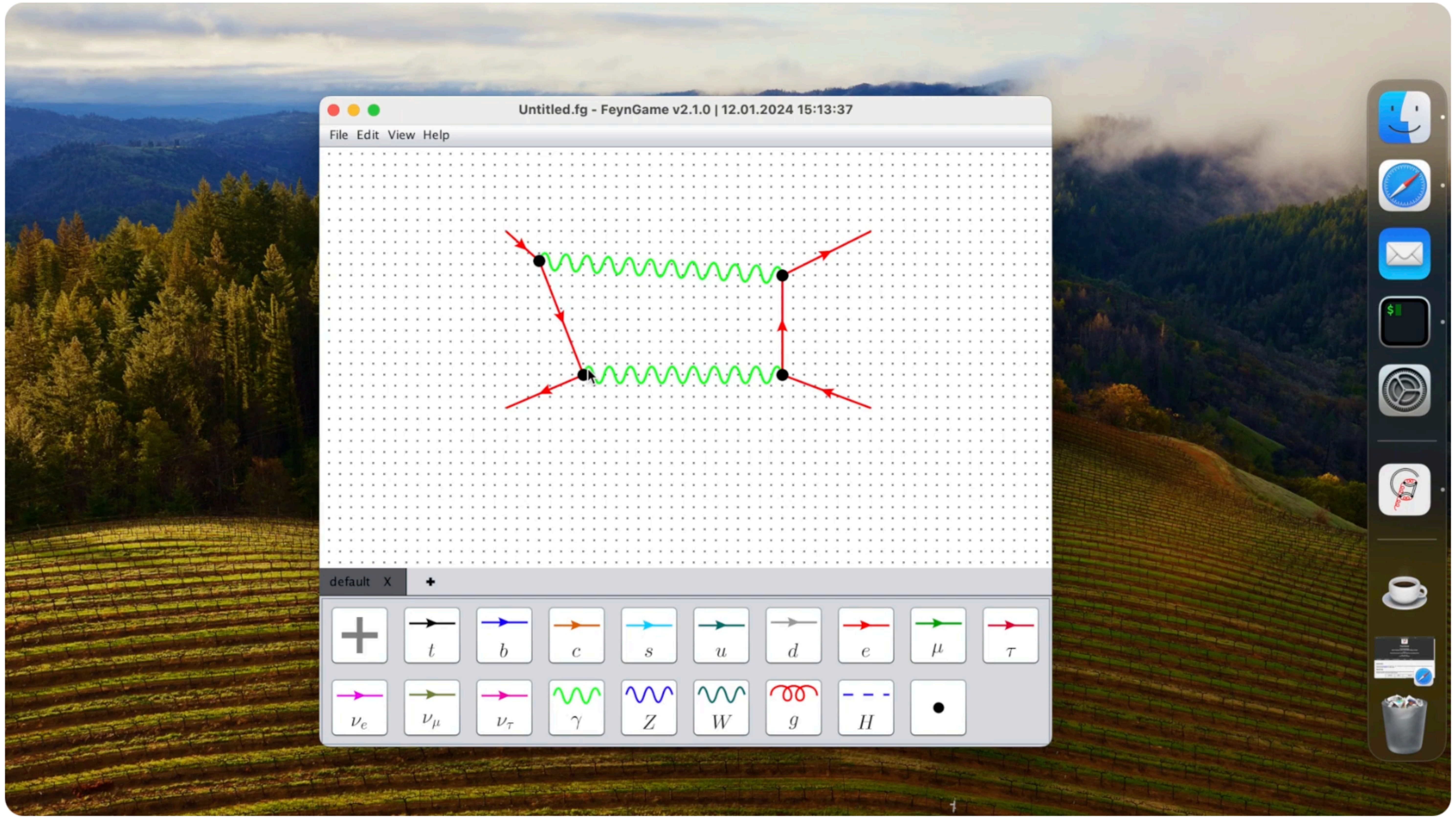

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This video shows you how easy it is to draw Feynman diagrams with FeynGame. Starting with a simple tree-level diagram, we can add loops, curve lines, choose different line styles, fine tune the shape, etc. FeynGame is available for free from here: https://web.physik.rwth-aachen.de/user/har...
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