

FeynRules

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in collaboration with N. D. Christensen and B. Fuks

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Tools 2010

Winchester, June 30th 2010

Outline

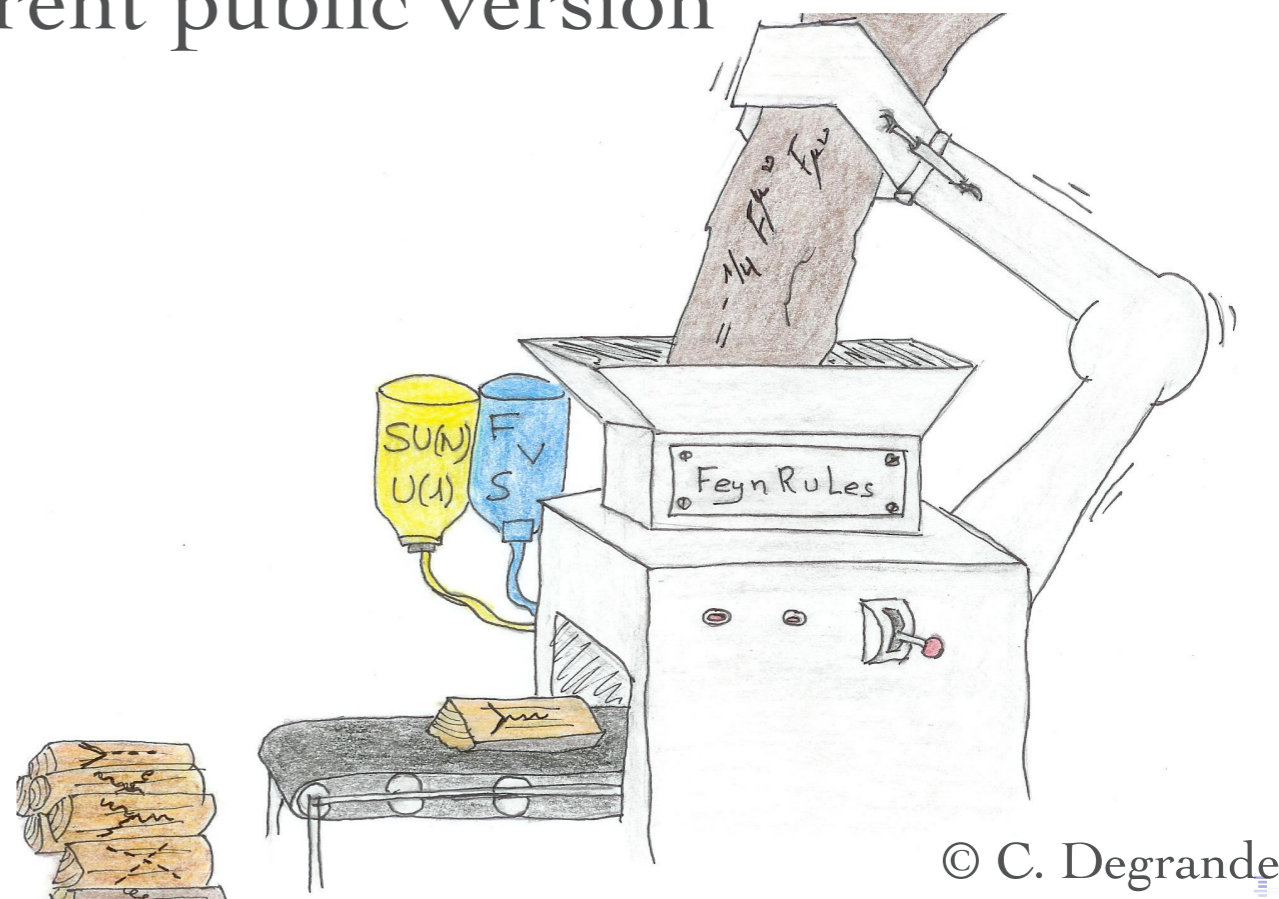
- What is FeynRules..?
- New developments:
 - ➔ New interfaces (FeynArts, Whizard, UFO)
 - ➔ Support for Weyl fermions and superfields
 - ➔ Diagonalization of mass matrices
- Live demonstration

What is FeynRules..?

- FeynRules is a *Mathematica* package that allows to derive Feynman rules from a Lagrangian.
- Current public version: 1.4.9, available from <http://feynrules.phys.ucl.ac.be>
- The only requirements on the Lagrangian are:
 - ➔ All indices need to be contracted (Lorentz and gauge invariance)
 - ➔ Locality
 - ➔ Supported field types: spin 0, 1/2, 1, 2 & ghosts

What is FeynRules..?

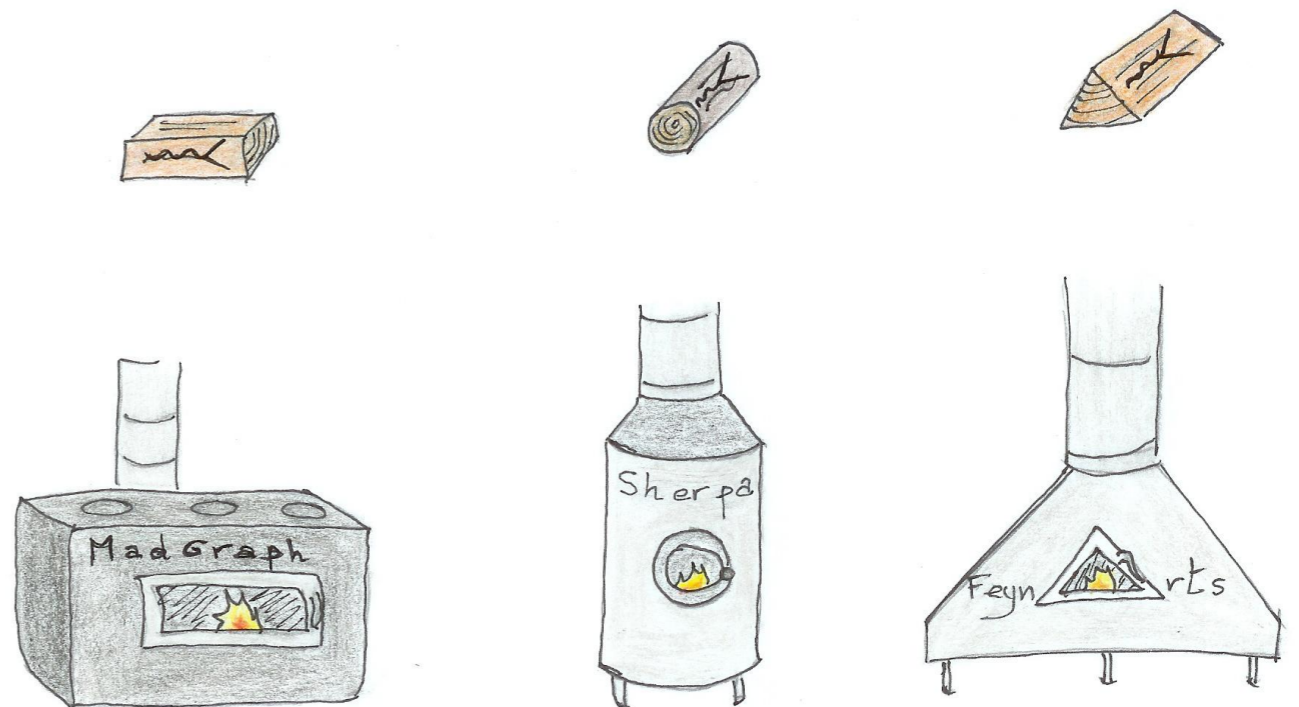
- FeynRules comes with a set of interfaces, that allow to export the Feynman rules to various matrix element generators.
- Interfaces coming with current public version
 - ➔ CalcHep / CompHep
 - ➔ FeynArts / FormCalc
 - ➔ MadGraph 4
 - ➔ Sherpa
 - ➔ Whizard / Omega



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How to use FeynRules

- The input requested from the user is twofold.

- **The Model File:**

Definitions of particles and parameters (e.g., a quark)

F[1] ==

```
{ClassName      -> q,  
 SelfConjugate -> False,  
 Indices        -> {Index[Colour]},  
 Mass           -> {MQ, 200},  
 Width         -> {WQ, 5} }
```

- **The Lagrangian:**

$$\mathcal{L} = -\frac{1}{4} G_{\mu\nu}^a G_a^{\mu\nu} + i\bar{q} \gamma^\mu D_\mu q - M_q \bar{q} q$$

L =

```
-1/4 FS[G,mu,nu,a] FS[G,mu,nu,a]  
+ I qbar.Ga[mu].del[q,mu]  
- MQ qbar.q
```

How to use FeynRules

- Once this information has been provided, FeynRules can be used to compute the Feynman rules for the model:

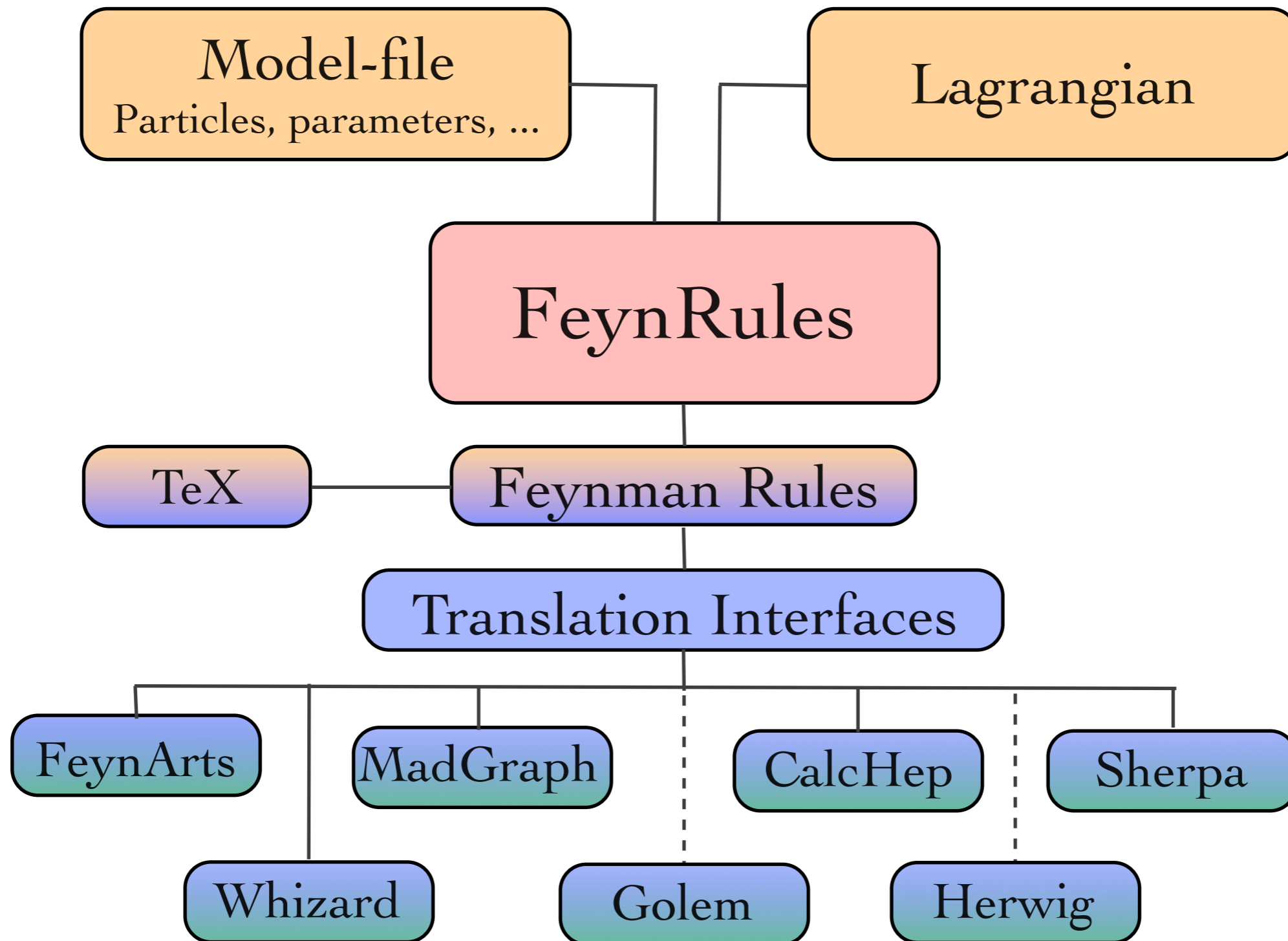
`FeynmanRules[L]`

- Equivalently, we can export the Feynman rules to a matrix element generator, e.g., for MadGraph 4,

`WriteMGOutput[L]`

- This produces a set of files that can be directly used in the matrix element generator (“plug ‘n’ play”).

FeynRules



New Developments

- In spring 2010, we locked up 13 experts in a room in a nice monastery for 5 days, and let them gather new ideas...
- As a result, many new projects got started (in fact too many to review them all here...)

Celine Sasha Priscila Martin Benj Christian Claude Will Olivier David Neil Thomas



Superfields (B. Fuks)

- In the future, FeynRules will allow the use of superfields.



- Example: Superpotential for left-handed quarks

$$\mathcal{W} = a_i Q_{Li} + M_{ij} Q_{Li} Q_{Lj} + \frac{1}{6} \lambda_{ijk} Q_{Li} Q_{Lj} Q_{Lk}$$

$$W = a[i] QL[i] + 1/2 * M[i, j] QL[i] QL[j] + 1/6 * I[i, j, k] QL[i] QL[j] QL[k]$$

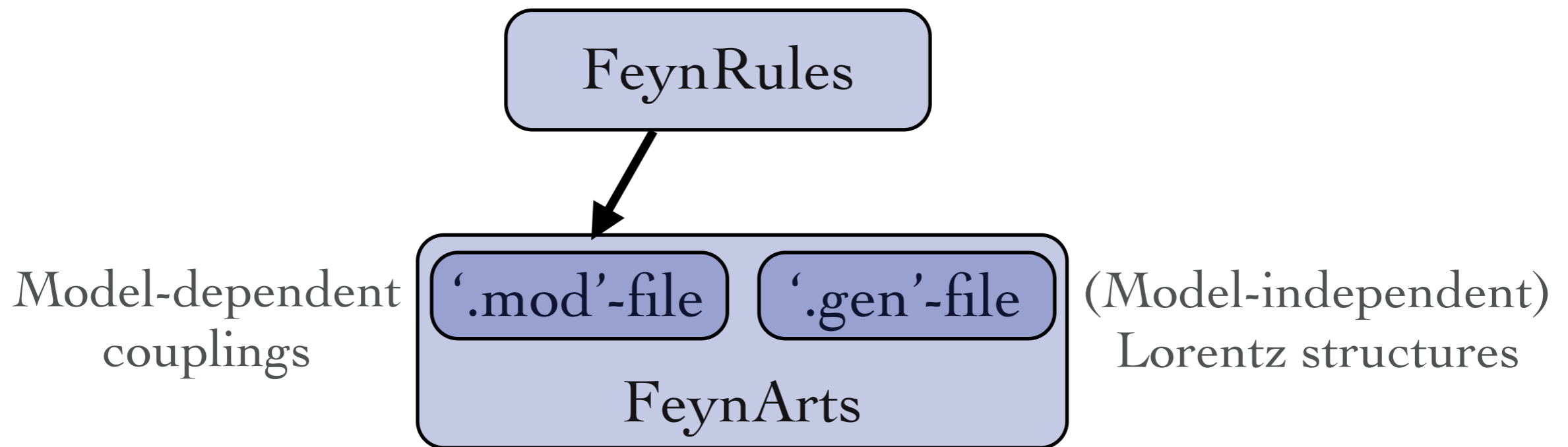
- FeynRules then converts the superfields into component fields:

SF2Components[W]

$$\begin{aligned} & -\frac{1}{6} \text{FTerm3}_i \text{sqL}_j \text{sqL}_k l_{i,j,k} - \frac{1}{6} \text{FTerm3}_k \text{sqL}_i \text{sqL}_j l_{i,j,k} - \frac{1}{6} \text{FTerm3}_j \text{sqL}_i \text{sqL}_k l_{i,j,k} \\ & - \frac{1}{6} \text{sqL}_j l_{i,j,k} \text{qL}_{\text{sp}\$2,i} \cdot \text{qL}_{\text{sp}\$2,k} - \frac{1}{6} \text{sqL}_i l_{i,j,k} \text{qL}_{\text{sp}\$2,j} \cdot \text{qL}_{\text{sp}\$2,k} - \frac{1}{2} M_{i,j} \text{qL}_{\text{sp}\$2,i} \cdot \text{qL}_{\text{sp}\$2,j} \end{aligned}$$

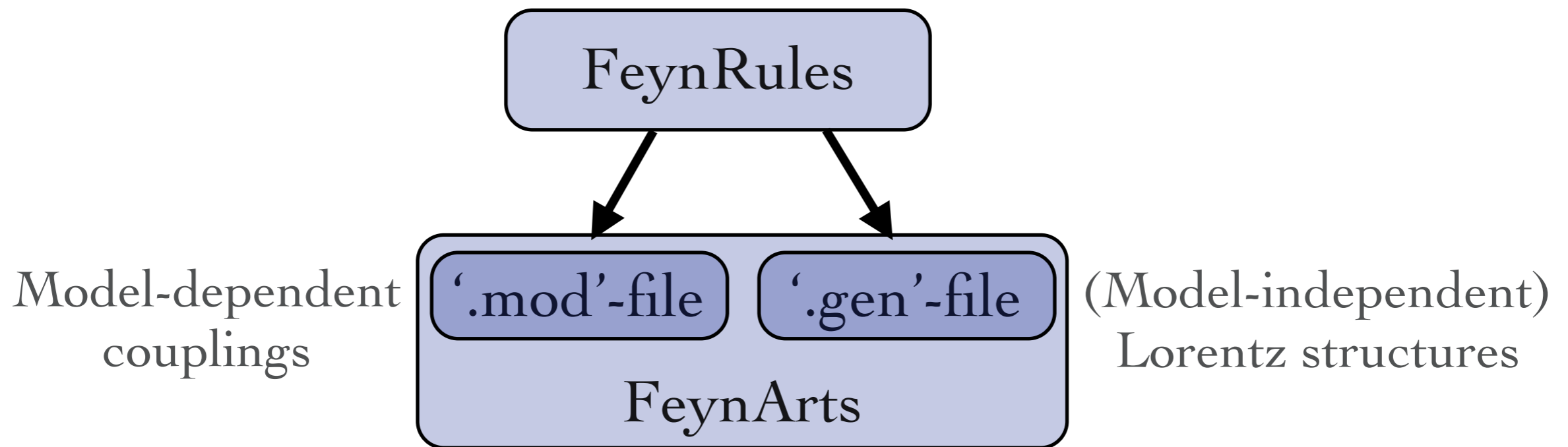
FeynArts interface (C. Degrande, CD)

- A new interface to FeynArts is being developed that allows to implement arbitrary Lorentz structures. 



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- This development goes along with a new version of FormCalc able to deal with multi-fermion interactions.

Mass Matrix diagonalization (N. Christensen, M. Wiebusch)

- In the future, FeynRules will perform the diagonalization automatically.

Input 1: Lagrangian

$$qLbar[s1,l1,f1,i].uR[s1,f2,i] Yu[f1,f2] Eps[l1,l2] Phibar[l2]$$

Input 2: Mixing relations

$$uq[s, \#, o] == CKMU.uqp[s, \#, o]$$

Output 1: Mass matrix to be diagonalized

$$\text{Diagonalization}(\text{HEigensystem}, \text{CKMU}, \{m_u, m_c, m_t\}) \rightarrow$$

Output 2: 'Rotation rules'

$$(P_+)_{s1,s} \left(\text{CKMU}(1, 1)^* uq_{s,1,o} + \text{CKMU}(2, 1)^* uq_{s,2,o} + \text{CKMU}(3, 1)^* uq_{s,3,o} \right)$$

- To be done: numerical code for the diagonalization.



The UFO

(P. de Aquino, CD, D. Grellscheid,
W. Link, O. Mattelaer, T. Reiter)



UFO = Universal FeynRules Output



- Idea: Create Python modules that can be linked to other codes and contain all the information on a given model.
- The UFO is a self-contained Python code, and not tied to a specific matrix element generator.
- Golem, MadGraph 5 and Herwig++ will use the UFO.
- The development of the UFO goes hand in hand with the development of ALOHA (Automatic Language-independent Output of Helicity Amplitudes), a code that allows to create HELAS routines from the UFO.

Implemented models

- Standard Model* (CD, N. Christensen)
- Most general two Higgs doublet model* (CD, M. Herquet)
- Minimal Higgsless Model* (N. Christensen)

* available at <http://feynrules.phys.ucl.ac.be>

- Validation of the models:

Process	MG-FR	MG-ST	CH-FR	CH-ST	SH-FR	SH-ST	WO-FR	WO-ST	Comparison
e+,e->sd1,sd1-	2.85002×10^{-2}	2.85011×10^{-2}	2.8501×10^{-2}	2.8501×10^{-2}	2.85007×10^{-2}	2.85007×10^{-2}	2.85013×10^{-2}	2.85013×10^{-2}	$\delta = 0.00394796 \%$
e+,e->sd2,sd2-	4.34049×10^{-4}	4.34207×10^{-4}	4.3415×10^{-4}	4.3415×10^{-4}	4.34145×10^{-4}	4.34145×10^{-4}	4.34155×10^{-4}	4.34155×10^{-4}	$\delta = 0.0364994 \%$
e+,e->sd1,sd2-	2.85795×10^{-4}	2.85759×10^{-4}	2.8578×10^{-4}	2.8579×10^{-4}	2.85825×10^{-4}	2.85825×10^{-4}	2.8579×10^{-4}	2.8579×10^{-4}	$\delta = 0.0229397 \%$
e+,e->n1,n1	7.45909×10^{-2}	7.45813×10^{-2}	7.4637×10^{-2}	7.4637×10^{-2}	7.46268×10^{-2}	7.46266×10^{-2}	7.463×10^{-2}	7.46338×10^{-2}	$\delta = 0.0746855 \%$
e+,e->n1,n2	2.5541×10^{-2}	2.55366×10^{-2}	2.5555×10^{-2}	2.5555×10^{-2}	2.55523×10^{-2}	2.55516×10^{-2}	2.55521×10^{-2}	2.55535×10^{-2}	$\delta = 0.0719985 \%$
e+,e->n1,n3	2.08218×10^{-3}	2.08034×10^{-3}	2.081×10^{-3}	2.081×10^{-3}	2.08093×10^{-3}	2.08089×10^{-3}	2.0811×10^{-3}	2.081×10^{-3}	$\delta = 0.0880299 \%$
e+,e->n1,n4	3.73046×10^{-3}	3.73254×10^{-3}	3.7325×10^{-3}	3.7325×10^{-3}	3.73208×10^{-3}	3.7321×10^{-3}	3.73223×10^{-3}	3.73238×10^{-3}	$\delta = 0.0555803 \%$

Implemented models: (Susy)

- Full MSSM* (B. Fuks)
- NMSSM (B. Fuks)
- R-symmetric MSSM (B. Fuks)
- RPV MSSM (B. Fuks)

* available at <http://feynrules.phys.ucl.ac.be>

Implemented models: (ED)

- Universal Extra Dimensions* (P. de Aquino)
- Large extra dimensions* (P. de Aquino)
- Randall-Sundrum I (P. de Aquino)

* available at <http://feynrules.phys.ucl.ac.be>

Implemented models: (Effective)

- Strongly interacting Little Higgs (C. Degrande)
- Composite Top model (C. Degrande)
- Chiral perturbation theory (C. Degrande)

* available at <http://feynrules.phys.ucl.ac.be>

Live demonstration

- Let us consider a simple model, just to get started...
- We will implement a model consisting of a Dirac octet ('Dirac gluino') decaying into triplet scalars ('squarks').

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{gluino} + \mathcal{L}_{squark} + \mathcal{L}_{decay}$$

$$\mathcal{L}_{gluino} = i\bar{\tilde{g}}\gamma^\mu D_\mu \tilde{g} - M_G \bar{\tilde{g}}\tilde{g}$$

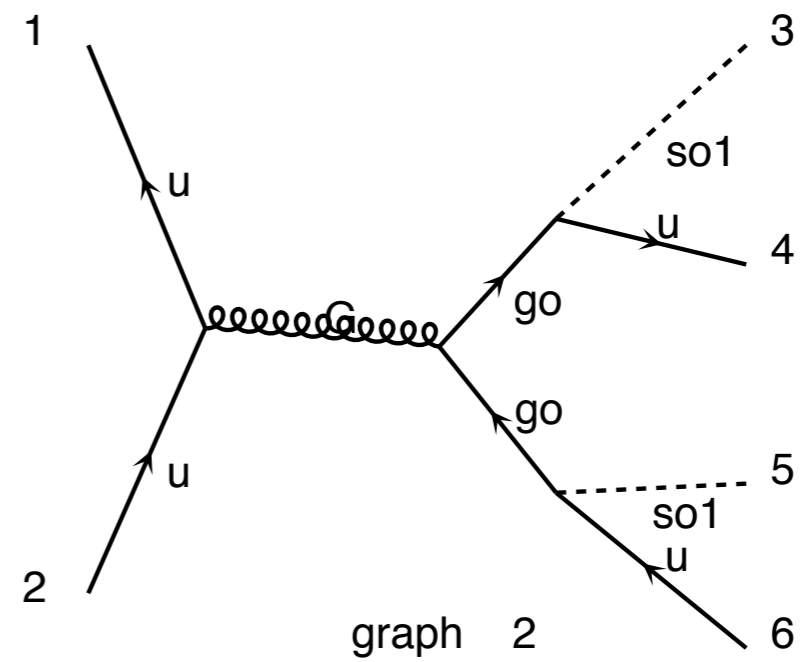
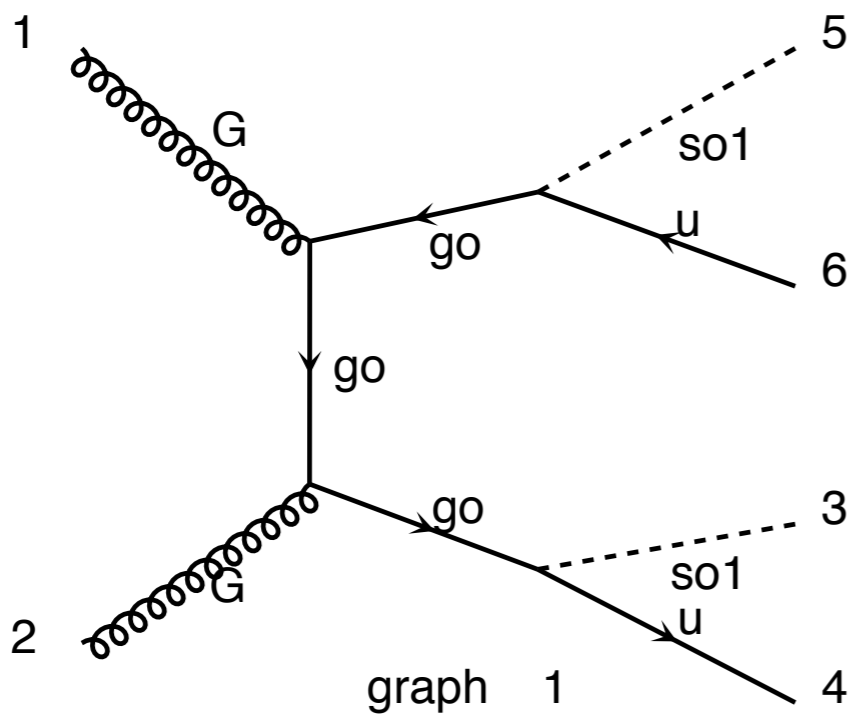
$$\mathcal{L}_{squark} = D^\mu \phi_k^\dagger D_\mu \phi_k - M_\phi^2 \phi_k^\dagger \phi_k$$

$$k = 1, 2, 3$$

$$\mathcal{L}_{decay} = g_s T_{ij}^a \bar{\tilde{g}}^a u_{R,jk} \phi_{ik}^\dagger + \text{h.c.}$$

	SU(3)	SU(2)	U(1)	Mass (GeV)
\tilde{g}	8	1	1	200
ϕ	3	1	2/3	150, 220, 250

Live demonstration



Towards a database of models...

The screenshot shows a web browser window with the address bar containing `https://moDel.org/1004.0123.html`. The browser's address bar also shows a search engine (Google) and a search icon. The browser's tab bar shows a single tab titled "[1004.0123] MSSM + Z'". The page content is as follows:

moDel.org > SuperSym > moDel:1004.1424 Search or Article-id [\(Help | Advanced search\)](#)

All papers

Supersymmetric models

MSSM + Z'

[Mr. X](#)

(Submitted on 14 Apr 2010)

We present the FeynRules implementation of the extension of the MSSM with a Z' boson. This model was first presented in [arXiv:1003.1234](#).

Comments: FeynRules model file (3 files) + 2 benchmark points (2 files)
Subjects: **MSSM - Extensions (SuperSym)**
Cite as: **moDel:1004.0123v1 [SuperSym]**

Validation

This model implementation is known to work with

- CalcHep
- Golem
- Herwig
- MadGraph
- Sherpa

Results of the validation are available [here](#).

Submission history

From: Mr. X [[view email](#)]
[v1] Wed, 14 Apr 2010 20:45:35 GMT (13kb)

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