

# Loopedia, a Database for Loop Integrals

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**Abstract.** Loopedia is a new database at [loopedia.org](http://loopedia.org) for Feynman integrals, providing both bibliographic information as well as results made available by the community. Its bibliometry is complementary to that of INSPIRE or arXiv, as it allows to search for integrals by graph-theoretical specifications, e.g. their topology.

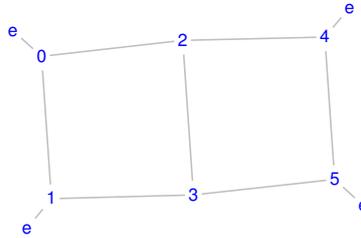
## 1. Introduction

Searching and accessing bibliographic information in high-energy physics is generally solved satisfactorily through databases such as INSPIRE and arXiv. The search within these databases is indexed by ‘traditional’ metrics: author, title, year of publication, etc. However, for the practitioner in loop calculations it is not easy to find e.g. publications which refer to a particular loop integral, where the integral is specified in some graph-theoretical way, say by its topology.

Loopedia [1] attempts to fill this gap, while not being limited to bibliographic information. The description field of each record can hold any kind of textual information (e.g. URLs to software), and in addition arbitrary files can be uploaded, for example Fortran programs or Maple worksheets.

## 2. Integrals and Graphs

Scalar Feynman loop integrals correspond to graphs and as such can be identified by a representation of the corresponding graph. A common choice is the *edge (adjacency) list*: each propagator (edge) is specified by the pair of vertices (nodes) it connects – external nodes need not be distinguished to identify the topology. For example, the following two-loop box graph has the edge list (e,0) (0,1) (0,2) (e,1) (1,3) (2,3) (2,4) (3,5) (e,4) (4,5) (e,5):



The Nickel index [2, 3, 4] provides an alternative representation which is constructed as follows: start at a vertex 0 and write down all vertices connected to 0 (**e** for external legs), then insert a '|'. Repeat the procedure for the other vertices but omit edges already included. For the two-loop box graph above this procedure leads to

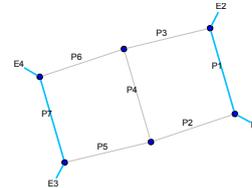
vertex	0	1	2	3	4	5
connected to	e12	e[0]3	[0]34	[12]5	e[2]5	e[34]

and hence its Nickel index is **e12|e3|34|5|e5|e|**.

The Nickel index provides a compact identifier and has therefore been chosen as the basic object by which integrals are indexed in Loopedia. Neither the edge list nor the Nickel index is unique, however, i.e. depending on the chosen labelling the same graph may have different edge lists/Nickel indices. Loopedia therefore canonicalizes all input.

Besides this 'bare' Nickel index, which represents just the topology of the graph, Loopedia introduces an augmented form, the colored Nickel index, *CNickel* for short, which additionally captures the configuration of masses and external  $q^2$ . Loopedia color-codes them on the screen:

Nickel **e12|e3|34|5|e5|e|**  
 CNickel **e12|e3|34|5|e5|e|:110|10|00|0|11|1|**



For each 'edge identifier' of the Nickel (**e** or a digit), the coloring has a mass identifier:

- 0 for zero,
- {z, n, s} for {any, non-zero, special} mass scale,
- 1...9, a...y (not n, s) for a definite non-zero mass scale.

The 's' option is for cases like thresholds or pseudo-thresholds, and the exact meaning of 'special' should be detailed in the description of the integral.

The 'definite' identifiers also represent arbitrary scales (though not zero) but unlike the 'zns' choices they express equality of scales within the graph, similar to named patterns in a computer-algebra system. The graph in the example above has several massive propagators/legs, but all with the same scale '1'.

### 3. User Guide

Loopedia is located at [loopedia.org](http://loopedia.org) and when accessed, the Start Page is displayed. One enters a graph in the input field and/or chooses constraints for the search with the lower control bars and then hits the  button.



**Graph e12|e3|45|45|e|e|**

Edit   Edit  Browse   Home

Edge list: (e,0) (0,1) (0,2) (e,1) (1,3) (2,4) (2,5) (3,4) (3,5) (e,4) (e,5)

Nickel index: e12|e3|45|45|e|e|

Database path: 2/4/7/e12|e3|45|45|e|e|

Propagator P1 any m

Propagator P2 any m

Propagator P3 any m

Propagator P4 any m

Propagator P5 any m

Propagator P6 any m

Propagator P7 any m

External Leg E1 any  $q^2$

External Leg E2 any  $q^2$

External Leg E3 any  $q^2$

External Leg E4 any  $q^2$

Choose Configuration

**Figure 2.** The Loopedia Configuration Editor

When editing a topology (bare Nickel index only) the page ends here, i.e. in order to proceed one needs to choose a configuration first. Otherwise the page continues with the available records and the New Record Form (Fig. 4).

### 3.3. Entering New Records

To enter a new record one must first navigate to a graph and a configuration as outlined above. The New Record Form is found beneath the available records.

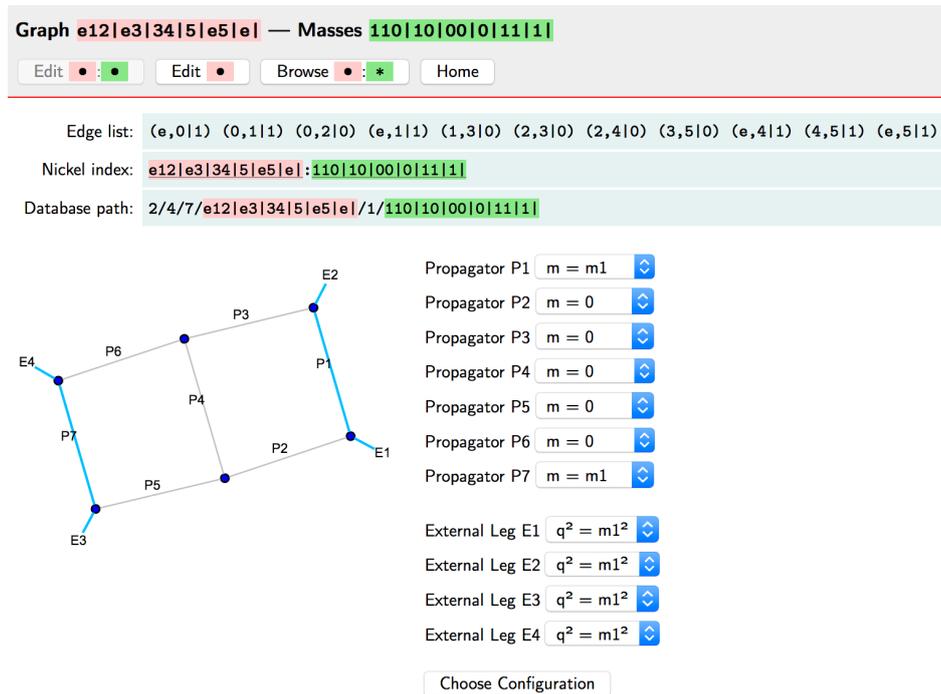
Upon successful submission the submitted record is displayed again for review, with controls for editing and deletion (Fig. 5). An e-mail is sent to the submitter's address with an individualized URL that allows to access the review page again for future editing.

The submitted records are not visible publicly before they have been confirmed by a moderator. This is a safety measure we implemented currently to prevent situations like submitters deleting each other's records; this may change in the future. The moderators are notified together with the submitter and will usually make new records public in a timely manner.

## 4. Internal structure

Loopedia is realized as a bash script in a CGI environment which uses the Unix file system as database and is indexed by the `mlocate` utility.

The database contains (in the real filesystem sense) one directory for each bare Nickel index, with subdirectories for the configuration index (the second part of the `CNickel`) of the same



**Figure 3.** The Loopedia Record Display

graph. Underneath comes another layer of subdirectories for the visibility (`public`, `private`, `deleted`), and below that, one directory for each record. The actual implementation inserts a few more directory layers for indexing and performance reasons so that the full database path becomes

$$\text{db}/L/\ell/p/\text{Nickel}/s/\text{Config}/\text{Visibility}/\text{Record}$$

where  $L$ ,  $\ell$ ,  $p$ ,  $s$  are the number of loops, legs, propagators, and scales, respectively. The database root ‘db’ is included in the path to be able to make anchored searches. Records have identifiers similar to the maildir format in Unix, e.g. 1482239373.Z1Fv. (Maildir stores each incoming e-mail in a separate file, whose name includes a timestamp, to avoid race conditions. For the same reason, we store each record in a separate folder.)

Almost all graph-theoretical operations in Loopedia are taken care of by the Python library GraphState [4]. GraphState allows to supplement a graph with configurations, i.e. add extra integers to either the nodes or the edges. The colored Nickel index used by Loopedia implements a single edge coloring which encodes masses and external  $q^2$ .

To draw the graph, a Python function translates the graph into Graphviz’s DOT language [7], from which neato produces an SVG image. SVG is an XML-based vector format rendered by all modern browsers and scales well in the icon-size plaquettes of the Graph Browser.

## 5. Summary

We presented a new database which allows to search for bibliographic and other information on loop integrals based on topology-related information. The intention of Loopedia is to collect the information available in the literature and to make it searchable by graph. It relies

**Integrand type:**  if *other*, please specify:

**Propagator powers** (the  $n$  in  $(p^2 - m^2)^{-n}$  for which result is valid, separate by comma if necessary, leave empty if n/a):  
P1  P2  P3  P4

**Order(s) in  $\epsilon$**  (separate by comma, empty if n/a):

**Reducible:**  **Number of master integrals:**

**Reference** (arXiv:yyymm.nnnnn or hep-xx/yyymmnnn preferred, empty if n/a):

**Relevant equations in reference:**

**Authors:**

**Description** (package URL, dimension computed in, type of functions, Euclidean/physical kinematics, weight, free text, etc.):

**Submitter** (e-mail):

**Additional material** (PDFs not on arXiv, Mathematica/Maple/FORM/Python/Fortran programs, etc.):

No file selected.  
 No file selected.  
 No file selected.

**Figure 4.** The New Record Form

<p><b>Reference:</b> <a href="#">arXiv:1612.05609</a></p> <p><b>Description:</b> The authors compute the planar 2-loop box master integrals involved in <math>QQ \rightarrow QQ</math>, where <math>QQ</math> are massive external quarks using the method of differential equations.</p> <p><b>Submitter:</b> <a href="mailto:sophia.borowka@cern.ch">sophia.borowka@cern.ch</a></p>	<p><b>Record 1482239373.Z1Fv</b>  added 20 Dec 2016 13:09 UTC  last modified 23 May 2017 14:07 UTC</p> <p><input type="button" value="edit"/> <input type="button" value="delete"/></p>
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This record is not publicly visible until confirmed by a moderator.

**Figure 5.** The Loopedia Record Review

on the concept that the community will actively contribute to the database by submitting new integral information. The database is hosted at the Max Planck Institute for Physics in Munich with broadband internet access and a daily backup at [loopedia.org](http://loopedia.org).

- [1] C. Bogner *et al.*, “Loopedia, a Database for Loop Integrals,” arXiv:1709.01266 [hep-ph].
- [2] J.F. Nagle, *J. Math. Phys.* **7** (1966) 1588.
- [3] B.G. Nickel, D.I. Meiron, G.A. Baker, Compilation of 2-pt and 4-pt graphs for continuous spin model, University of Guelph report, 1977.
- [4] D. Batkovich, Y. Kirienko, M. Kompaniets, S. Novikov, arXiv:1409.8227.  
The GraphState library is at <https://pypi.python.org/pypi/GraphState>.
- [5] J. Küblbeck, M. Böhm, A. Denner, *Comput. Phys. Commun.* **60** (1990) 165;  
T. Hahn, *Comput. Phys. Commun.* **140** (2001) 418 [hep-ph/0012260].
- [6] P. Nogueira, *J. Comput. Phys.* **105** (1993) 279
- [7] E.R. Gansner, S.C. North, *Software - Practice and Experience* **30** (2000) 1203, [graphviz.org](http://graphviz.org).