



A database and a web resource for
studying recurrent interaction
networks in RNA structures

<http://carnaval.lri.fr>

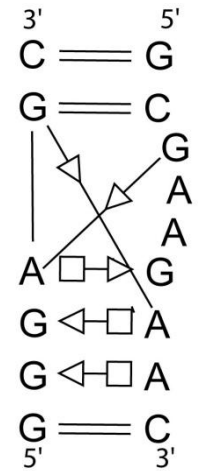
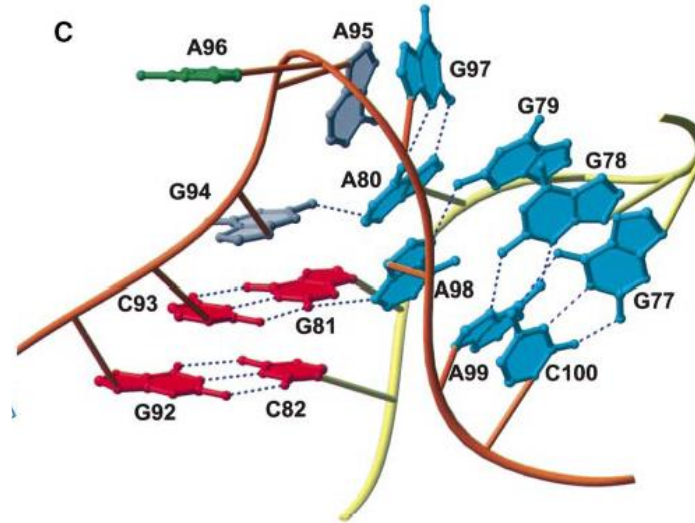
Alain Denise

Université Paris-Sud – CNRS – Université Paris-Saclay

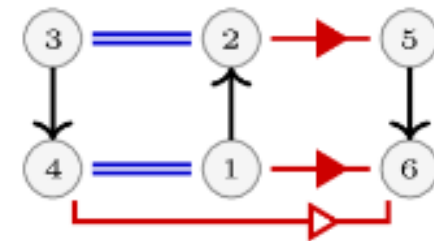
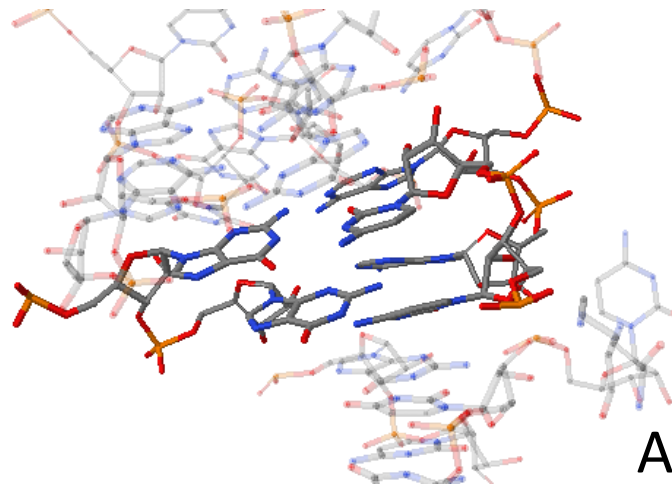
RNA tertiary motifs

They are mostly composed of noncanonical interactions

They can mediate the 3D folding of the molecule, they can also be sites for chemical synthesis.



Kink-turn

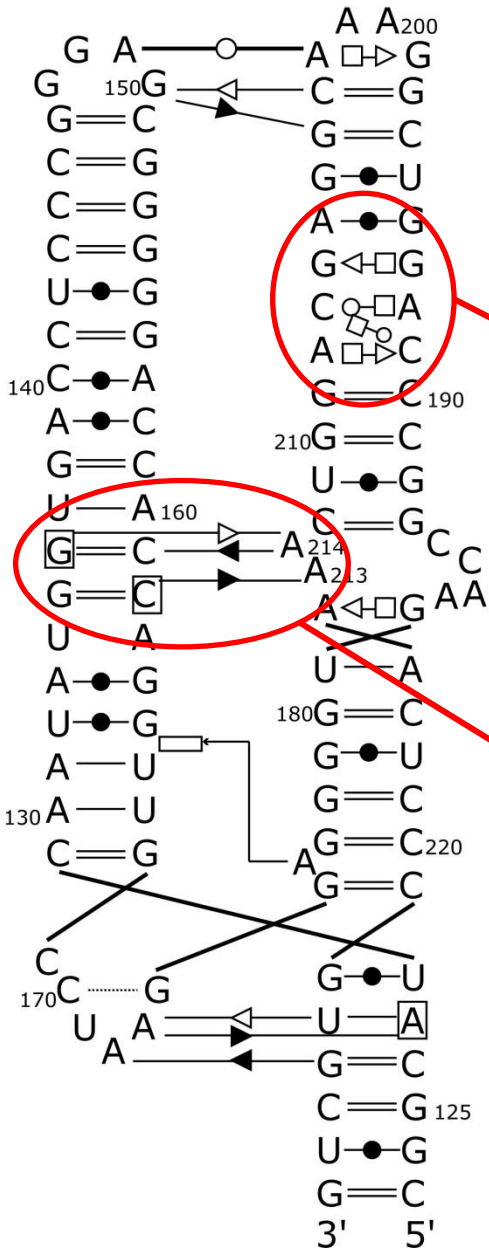


A-minor type I/II

Local and distant motifs

Local: within a secondary structure element.

Distant: connects 2 distinct secondary structure elements.



S Domain SRP

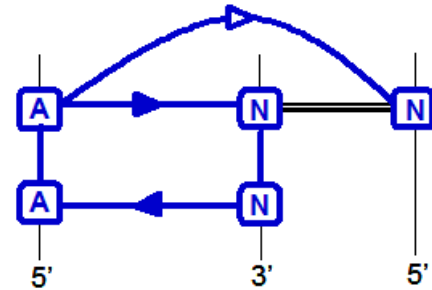
Databases for RNA structural motifs

- RNA 3D Motif Atlas (Petrov et al. 2013)
- RNA Bricks (Chojnowski et al. 2014)
- ...
- But neither automatic detection nor comprehensive database for distant motifs until recently.

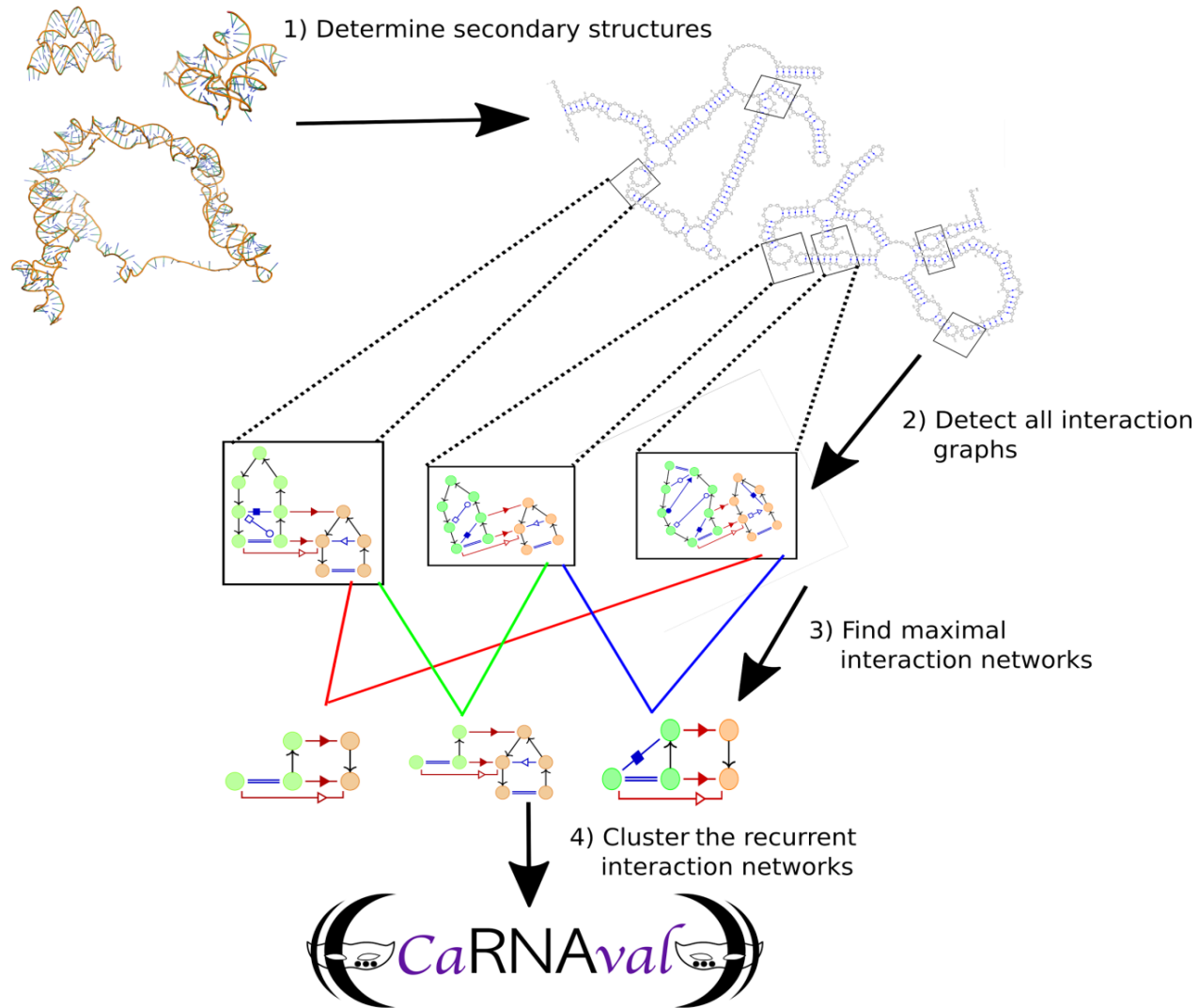


Recurrent Interaction Networks (RINs)

- **Definition:** remember Benasque 2015 😊
... or read the paper (NAR 2018)
- **Main properties:**
 - An interaction network **connects two secondary structure elements (SSEs)**
 - An interaction network is **recurrent** if it appears at least twice in a non redundant set of RNAs.
 - The **context** is important (flanking interactions and nucleotides)
 - An interaction network can be **modular**, *i.e.* it can contain smaller interaction networks.



Automated extraction and classification pipeline



Data and statistics

- All non-redundant structures in RNA3DHub (<http://rna.bgsu.edu/rna3dhub>) version 2.92, September 2016, at 3.0 Å resolution.
- Some statistics:
 - **845 structures** extracted from the PDB, containing 912 RNA chains identified as non-redundant
 - 1426 pairs of SSEs connected by long range interactions
 - **337 recurrent interaction networks (RINs)** found; from **2 to 257 occurrences** of each.

Home page



Organized collection of Recurrent Interaction Networks (RIN)
in all experimentally determined RNA structures
with proper display tools

carnaval.lri.fr

Info	All RINs
Adjacent SSEs RINs	Distant SSEs RINs
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All RINs

Pseudoknot mesh

A-minor mesh

A-minor type I

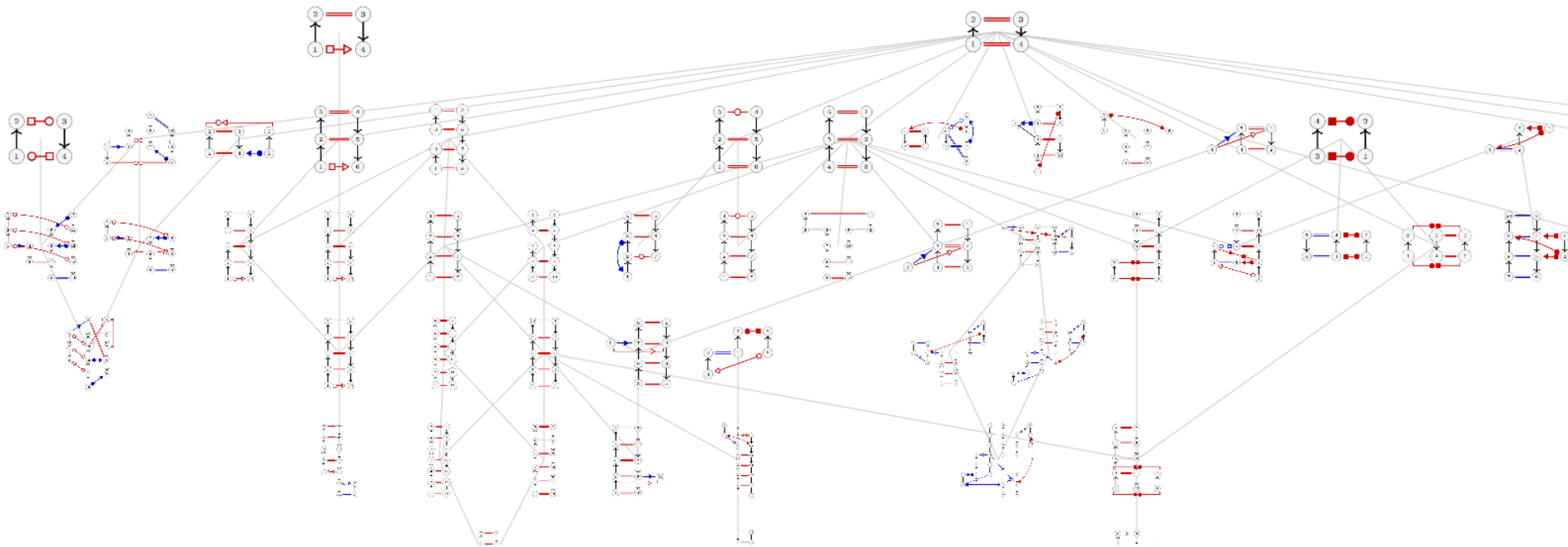
A-minor type I/II

trans-W-C/H mesh

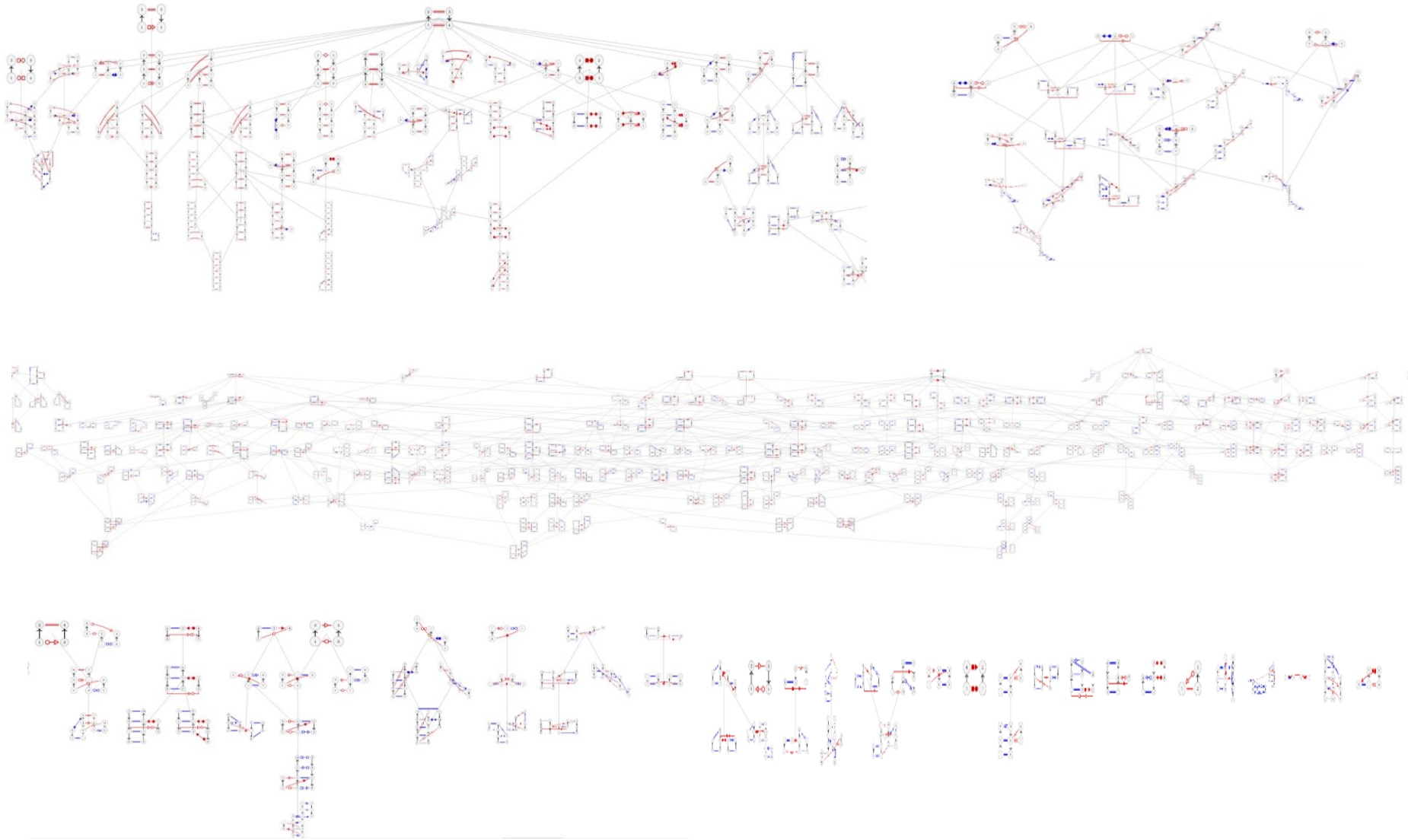
Ribose zipper

GNRA

A-rich loop



All RINs with their inclusion relations



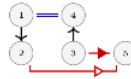
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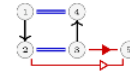
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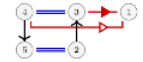
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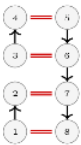
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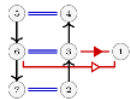
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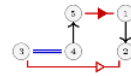
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#7
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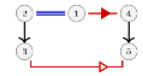
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#9
139



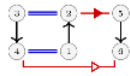
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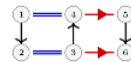
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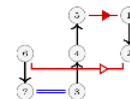
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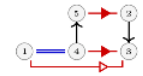
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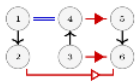
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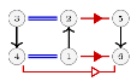
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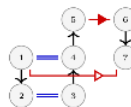
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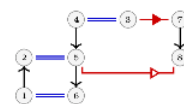
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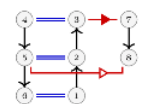
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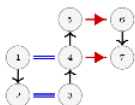
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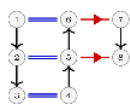
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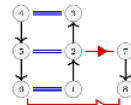
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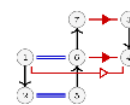
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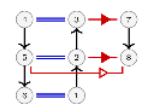
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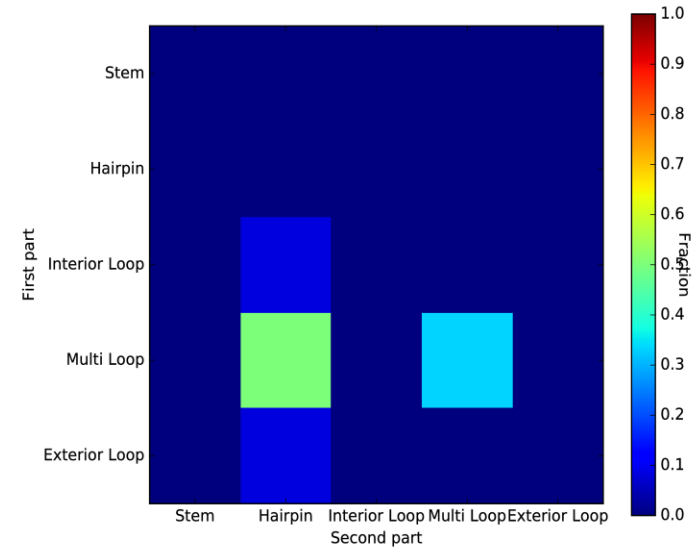
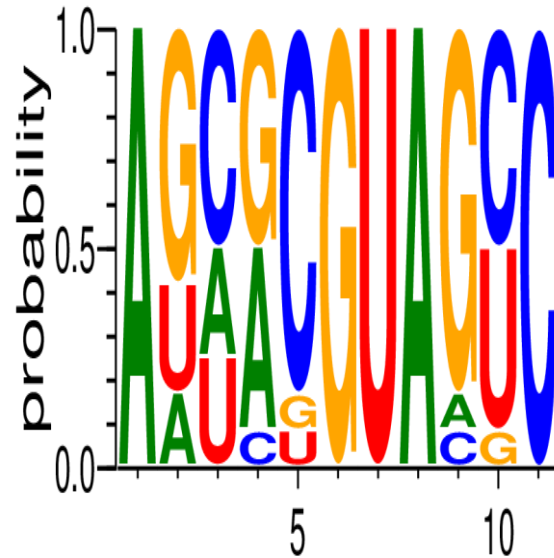
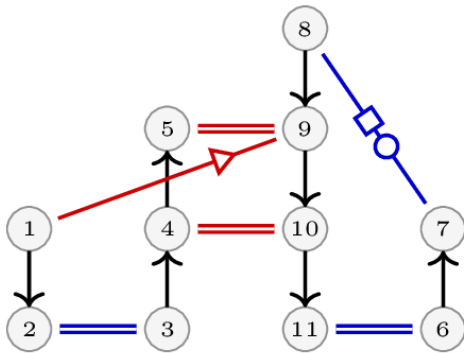


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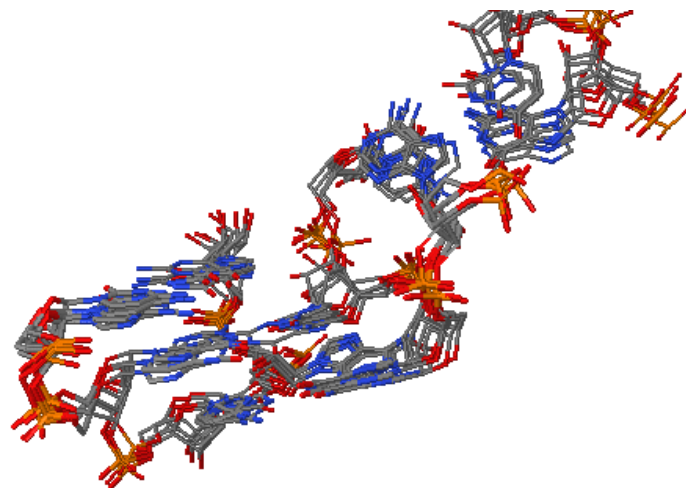


RIN #78 : general information

12 occurrences

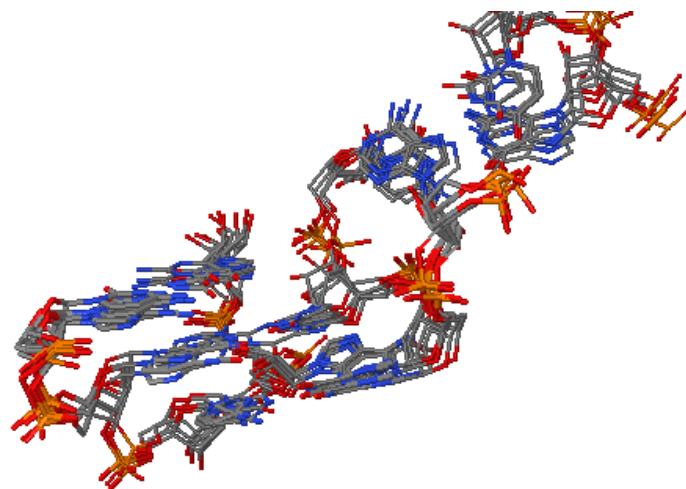


RIN #78 : locations and 3D alignment



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<input checked="" type="checkbox"/>	5J7L_DA_1	AGCGCGUAGCC	Structure of the 70s e coli ribosome with the u1052g mutation in the 16s rrna bc
<input checked="" type="checkbox"/>	4RGE_B_2	AUAGCGUAGCC	Crystal structure of the in-line aligned env22 twister ribozyme
<input checked="" type="checkbox"/>	4V9F_0_3	AGCGUGUAACC	The re-refined crystal structure of the haloarcula marismortui large ribosomal s
<input checked="" type="checkbox"/>	3F2Q_X_4	AUAACGUAGUC	Crystal structure of the fmn riboswitch bound to fmn
<input type="checkbox"/>	4V9F_0_5	AGUACGUAGUC	The re-refined crystal structure of the haloarcula marismortui large ribosomal s
<input type="checkbox"/>	5FDU_1A_6	AGCGCGUAGCC	Crystal structure of the metalnikowin i antimicrobial peptide bound to the therm
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<input type="checkbox"/>	5DM6_X_8	AGCACGUAGUC	Crystal structure of the 50s ribosomal subunit from deinococcus radiodurans
<input type="checkbox"/>	4V9F_0_9	AAUGCGUAGCC	The re-refined crystal structure of the haloarcula marismortui large ribosomal s
<input type="checkbox"/>	4FRG_B_10	AGCAGGUACUC	Crystal structure of the cobalamin riboswitch aptamer domain
<input type="checkbox"/>	4OJI_A_11	AAUGCGUAGCC	Crystal structure of twister ribozyme

RIN #78 : locations and 3D alignment



<input checked="" type="checkbox"/>	5FDU_1A_0	AGCCCGUAGGC	Crystal structure of the metalnikowin i antimicrobial peptide bound to the therm
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<input checked="" type="checkbox"/>	3F2Q_X_4	AU	
<input type="checkbox"/>	4V9F_0_5	AG	ge ribosomal s
<input type="checkbox"/>	5FDU_1A_6	AG	d to the therm
<input type="checkbox"/>	4V88_A5_7	AU	
<input type="checkbox"/>	5DM6_X_8	AGCACGUAGUC	Crystal structure of the 50s ribosomal subunit from deinococcus radiodurans
<input type="checkbox"/>	4V9F_0_9	AAUGCGUAGCC	The re-refined crystal structure of the haloarcula marismortui large ribosomal s
<input type="checkbox"/>	4FRG_B_10	AGCAGGUACUC	Crystal structure of the cobalamin riboswitch aptamer domain
<input type="checkbox"/>	4OJI_A_11	AAUGCGUAGCC	Crystal structure of twister ribozyme

- 8 in ribosomes,
- 2 in twister ribozyme
- 2 in riboswitches (colabamin, FMN).

Rin #78: all occurrences information

RNA: [5FDU](#), Chain: 1A

Crystal structure of the metalnikowin i antimicrobial peptide bound to the thermus thermophilus 70s ribosome

+++Long Range Interactions+++

1389 G TSS 1430 A

1389 G CWW 1450 C

1390 G CWW 1449 C

1430 A TSS 1389 G

1449 C CWW 1390 G

1450 C CWW 1389 G

+++Local Motif: Multi Loop+++

1430 A B53 1431 G

1431 G CWW 1448 C

1448 C B53 1449 C

1449 C B53 1450 C

+++Local Motif: Multi Loop+++

1388 A B53 1389 G

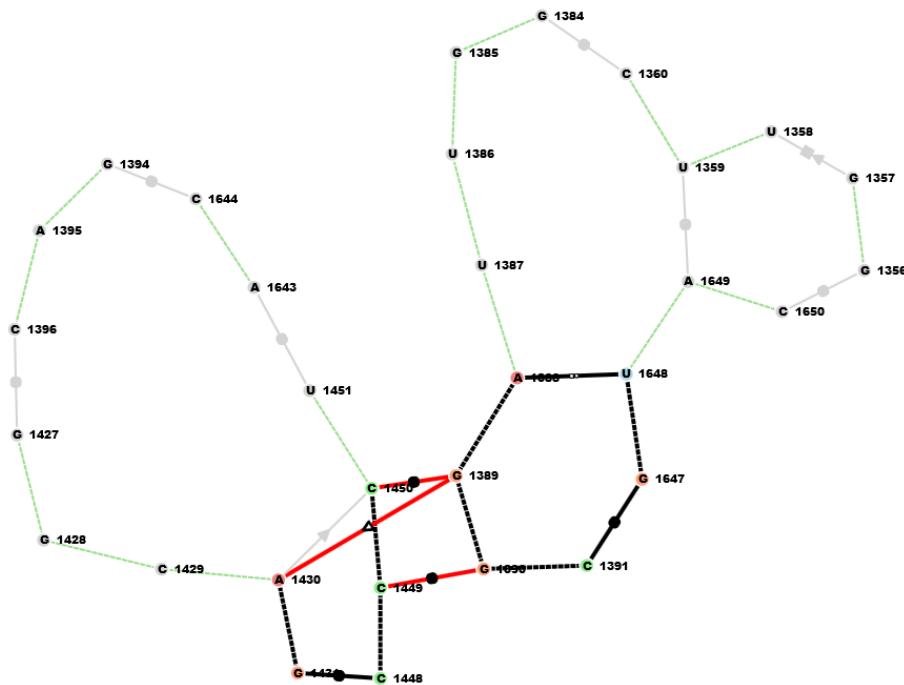
1388 A THW 1648 U

1389 G B53 1390 G

1390 G B53 1391 C

1391 C CWW 1647 G

1647 G B53 1648 U



Other features

Info	All RINs
Adjacent SSEs RINs	Distant SSEs RINs
Catalogs	Upload
Filter by interactions	Filter by PDBs
Download dataset	Benefactors

I want to see all RINs of the database which have at least three distant cSS interactions and one distant tSS interaction.

Other features

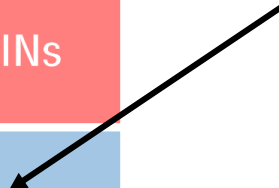
Info	All RINs
Adjacent SSEs RINs	Distant SSEs RINs
Catalogs	Upload
Filter by interactions	Filter by PDBs
Download dataset	Benefactors

I want to know which RINS are present in *2GDI Y*, *4P9R A* pdb structures.

Other features

Info	All RINs
Adjacent SSEs RINs	Distant SSEs RINs
Catalogs	Upload
Filter by interactions	Filter by PDBs
Download dataset	Benefactors

I want to know which RINs are present in **my** RNA structure (in CIF format) .



Other features

Info	All RINs
Adjacent SSEs RINs	Distant SSEs RINs
Catalogs	Upload
Filter by interactions	Filter by PDBs
Download dataset	Benefactors

I want all the data in my computer.

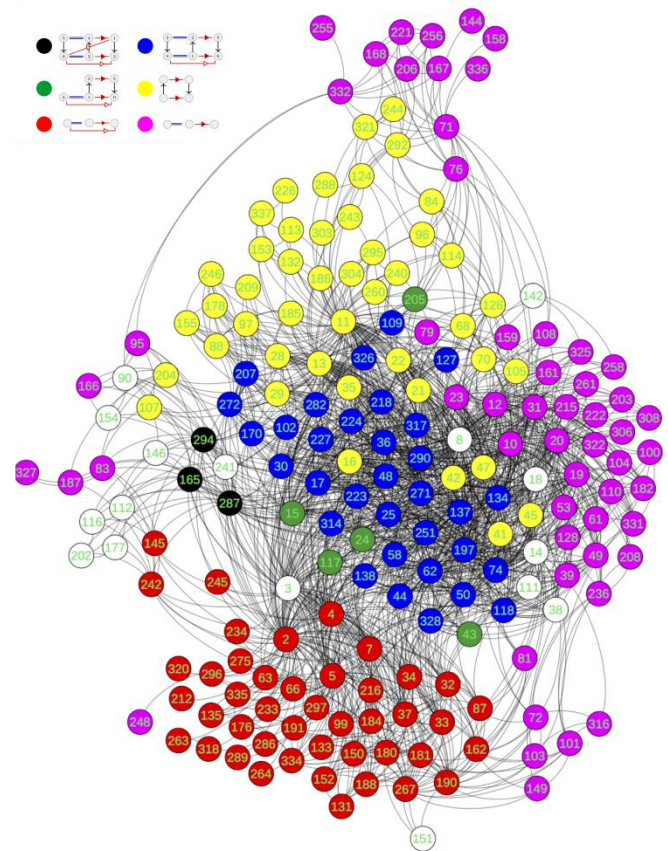
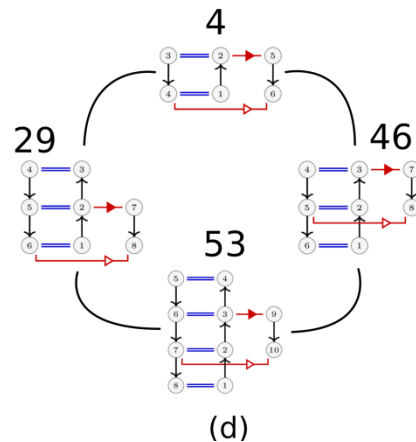
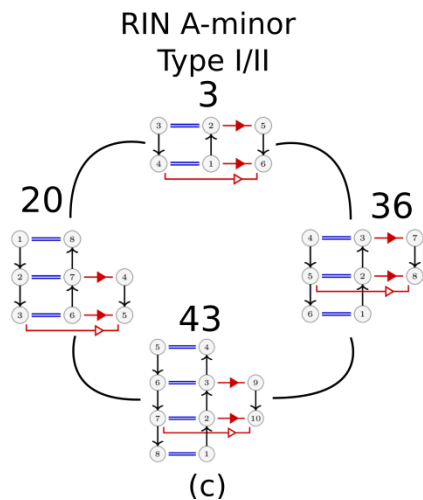
Mining for recurrent long-range interactions in RNA structures reveals embedded hierarchies in network families

Vladimir Reinhartz, Antoine Soulé, Eric Westhof, Jérôme Waldispühl, Alain Denise 

Nucleic Acids Research, Volume 46, Issue 8, 4 May 2018, Pages 3841–3851,

<https://doi.org/10.1093/nar/gky197>

- Pipeline / algorithms
- RINs' global analysis



Perspectives

- CaRNAval 2 (hopefully before Benasque 2021)!
 - Local motifs, (classical) RINs, generalised RINs (more than two SSEs)
 - Much faster extraction algorithm.
- Structure prediction, structure design...



Vladimir Reinharz, Antoine Soulé, Eric Westhof, Jérôme Waldispühl, Alain Denise



Also thanks to : Yann Ponty, Anton Petrov, Neocles Leontis.



Thanks !