

5. Some Problems in Heaven

Unfortunately, $\dim \mathcal{A}(\mathcal{X}, X) = \dim \Lambda(\mathcal{X}, X) = 4^{|\mathcal{X}|}$ is big. Fortunately, we have the following theorem, a version of one of the main results in Halacheva's thesis, [Ha1, Ha2]:

Theorem. Working in $\Lambda(\mathcal{X} \cup X)$, if $w = \omega e^\lambda$ is a balanced Gaussian (namely, a scalar ω times the exponential of a quadratic $\lambda = \sum_{\zeta \in \mathcal{X}, z \in X} \alpha_{\zeta, z} \zeta z$), then generically so is $c_{x, \xi} e^\lambda$. (This is great news! The space of balanced quadratics is only $|\mathcal{X}||X|$ -dimensional!)

Proof. Recall that $c_{x, \xi}: (1, \xi, x, x\xi)w' \mapsto (1, 0, 0, 1)w'$, write $\lambda = \mu + \eta x + \xi y + \alpha \xi x$, and ponder $e^\lambda =$

$$\dots + \frac{1}{k!} \underbrace{(\mu + \eta x + \xi y + \alpha \xi x)(\mu + \eta x + \xi y + \alpha \xi x) \cdots (\mu + \eta x + \xi y + \alpha \xi x)}_{k \text{ factors}} + \dots$$

Then $c_{x, \xi} e^\lambda$ has three contributions:

- ▶ e^μ , from the term proportional to 1 (namely, independent of ξ and x) in e^λ
- ▶ $-\alpha e^\mu$, from the term proportional to $x\xi$, where the x and the ξ come from the same factor above.
- ▶ $\eta y e^\mu$, from the term proportional to $x\xi$, where the x and the ξ come from different factors above.

So $c_{x, \xi} e^\lambda = e^\mu(1 - \alpha + \eta y) = (1 - \alpha)e^\mu(1 + \eta y/(1 - \alpha)) = (1 - \alpha)e^{\mu + \eta y/(1 - \alpha)}$.

□

Γ -calculus.

Thus we have an almost-always-defined “ Γ -calculus”: a contraction algebra morphism $\mathcal{T}(\mathcal{X}, X) \rightarrow R \times (\mathcal{X} \otimes_{R/R} X)$ whose behaviour under contractions is given by

$$c_{x, \xi}(\omega, \lambda = \mu + \eta x + \xi y + \alpha \xi x) = ((1 - \alpha)\omega, \mu + \eta y/(1 - \alpha)).$$

(Γ is fully defined on pure tangles – tangles without closed components – and hence on long knots).

Multiplying and comparing Γ objects:

```

Γ /: Γ[is1_, os1_, cs1_, ω1_, λ1_] × Γ[is2_, os2_, cs2_, ω2_, λ2_] :=
  Γ[is1 ∪ is2, os1 ∪ os2, Join[cs1, cs2], ω1 ω2, λ1 + λ2]
Γ /: Γ[is1_, os1_, ω1_, λ1_] ≡ Γ[is2_, os2_, ω2_, λ2_] :=
  TrueQ[Sort@is1 == Sort@is2] ∧ (Sort@os1 == Sort@os2) ∧
  Simplify[ω1 == ω2] ∧ CF@λ1 == CF@λ2

```

No rules for linear operations!

The crossings and the point:

```

Γ[Xi,j,k,l[S-, T-]] := Γ[{l, i}, {j, k}, <ξi → S, xj → T, xk → S, ξl → T>,
  T-1/2, CF[{ξl, ξi}.(1 1 - T; 0 T).{xj, xk}]];
Γ[X̄i,j,k,l[S-, T-]] := Γ[{i, j}, {k, l}, <ξi → S, ξj → T, xk → S, xl → T>,
  T1/2, CF[{ξi, ξj}.(T-1 0; 1 - T-1 1).{xk, xl}]];
Γ[Xi,j,k,l] := Γ[Xi,j,k,l[τi, τl]];
Γ[X̄i,j,k,l] := Γ[X̄i,j,k,l[τi, τj]];
Γ[Pi,j[T-]] := Γ[{i}, {j}, <ξi → T, xj → T>, 1, ξi xj];
Γ[Pi,j] := Γ[Pi,j[τi]];

```

6. An Implementation of Γ .

If I didn't implement I wouldn't believe myself.

Written in Mathematica [Wo], available as the notebook Gamma.nb at <http://drorbn.net/mo21/ap>. Code lines are highlighted in grey, demo lines are plain. We start with canonical forms for quadratics with rational function coefficients:

```

CCF[ξ_] := Factor[ξ];
CF[ξ_] := Module[{vs = Union@Cases[ξ, {ξ | x}_, ∞]},
  Total[(CCF[#][2]] (Times @@ vsPower[#]) & /@ CoefficientRules[ξ, vs]]];

```

Contractions:

```

ch,t@Γ[is_, os_, cs_, ω_, λ_] := Module[{α, η, γ, μ},
  α = D[ξt, xh]; μ = λ /. ξt | xh → 0;
  η = D[xh, λ] /. ξt → 0; γ = D[ξt, λ] /. xh → 0;
  Γ[
    DeleteCases[is, t], DeleteCases[os, h], KeyDrop[cs, {xh, ξt}],
    CCF[(1 - α) ω], CF[μ + η γ / (1 - α)]
  ] /. If[MatchQ[cs[ξt], τ_], cs[ξt] → cs[xh], cs[xh] → cs[ξt]];
c@Γ[is_, os_, cs_, ω_, λ_] := Fold[cm2,m2[#1] &, Γ[is, os, cs, ω, λ], is ∩ os]

```

Automatic intelligent contractions:

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Γ[{γ- T}] := c[γ];
Γ[{γ1 T, γ2 T}] := Module[{γ2},
  γ2 = First@MaximalBy[{γS}, Length[γ1[[1] ∩ #][2]] + Length[γ1[[2] ∩ #][1]] &];
  Γ[Join[{c[γ1 γ2], DeleteCases[{γS}, γ2]}]]];
Γ[os_List] := Γ[Γ /@ os]

```