Sum_1

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This file contains the details on the n = 1 case, to be merged into the main file as soon as they become polished enough.

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Let us denote by $\operatorname{Fam}_0(\mathbb{C})$ the set of equivalence classes of finite groupoids equipped with functors to \mathbb{C} (seen as a trivial category). In other words, a representative of an element of $\operatorname{Fam}_0(\mathbb{C})$ is a pair (X, f) consisting of a finite groupoid X together with a map $f : \pi_0(X) \to \mathbb{C}$. The map

$$Sum_0: Fam_0 \to \mathbb{C}$$

is defined as

$$\operatorname{Sum}_0(X, f) = \sum_{[x] \in \pi_0(X)} \frac{f(x)}{|\operatorname{Aut}(x)|}.$$

We will also use the more evocative notation

$$\int_X f(x)d\mu(x)$$

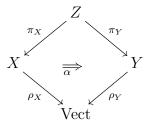
to denote $Sum_0(X, f)$. Notice that Sum_0 is linear in the f variable.

Remark 1.1. A function $f: \pi_0(X) \to \mathbb{C}$ can equivalently be seen as an element in $\operatorname{End}_{[X,\operatorname{Vect}]}(\mathbf{1}_X)$, where $\mathbf{1}_X\colon X \to \operatorname{Vect}$ is the constant functor taking the value \mathbb{C} on X. The map Sum_0 can therefore be seen as the datum of a map

Sum₀: End_[X,Vect](
$$\mathbf{1}_X$$
) $\to \mathbb{C}$,

for any finite groupoid X.

Definition 1.2. The category $\operatorname{Fam}_1(\operatorname{Vect})$ has as its objects finite groupoids equipped with functors to Vect, i.e., pairs (X, ρ) consisting of a finite groupoid X together with a functor $\rho \colon X \to \operatorname{Vect}$. Morphisms in $\operatorname{Fam}_1(\operatorname{Vect})$ are spans of groupoids over Vect, i.e., commutative diagrams



where the natural transformation $\alpha: \rho_X \circ \pi_X \to \rho_Y \circ \pi_Y$ is part of the data of the commutative diagram.

Remark 1.3. The identity mophisms and the composition of morphisms in $Fam_1(Vect)$ will be defined later.

For every object (X, ρ) in $\operatorname{Fam}_1(\operatorname{Vect})$ we can consider the vector space

$$[\mathbf{1}_X, \rho] = \operatorname{Hom}_{[X, \operatorname{Vect}]}(\mathbf{1}_X, \rho).$$

If $f: Y \to X$ is a functor between finite groupoids, and $\rho: X \to \text{Vect}$ is a functor, we write $f^*\rho: Y \to \text{Vect}$ for the functor $\rho \circ f$. If $\alpha: \mathbf{1}_X \to \rho$ is a natural transformation, then $f^*\alpha$ is a natural transformation between $f^*\mathbf{1}_X = \mathbf{1}_Y$ and $f^*\rho$. This defines a linear map

$$f^* \colon [\mathbf{1}_X, \rho] \to [\mathbf{1}_Y, f^* \rho].$$

Similarly, we can consider the vector space

$$[\rho, \mathbf{1}_X] = \operatorname{Hom}_{[X, \operatorname{Vect}]}(\rho, \mathbf{1}_X)$$

together with the linear map (also denoted f^* by slight abuse of notation)

$$f^* \colon [\rho, \mathbf{1}_X] \to [f^*\rho, \mathbf{1}_Y].$$

Passing to the linear duals we get the linear map

$$(f^*)^{\vee} \colon [f^*\rho, \mathbf{1}_Y]^{\vee} \to [\rho, \mathbf{1}_X]^{\vee}.$$

Next, notice that composition of morphisms gives a bilinear map

$$[\mathbf{1}_X, \rho] \otimes [\rho, \mathbf{1}_X] \to [\mathbf{1}_X, \mathbf{1}_X]$$

and so composing this with the linear map $\operatorname{Sum}_0(X, -) \colon [\mathbf{1}_X, \mathbf{1}_X] \to \mathbb{C}$ we get a bilinear pairing $\langle \, | \, \rangle_X$ between $[\mathbf{1}_X, \rho]$ and $[\rho, \mathbf{1}_X]$. Equivalently, this is a linear map

$$\delta_{(X,\rho)} \colon [\mathbf{1}_X, \rho] \to [\rho, \mathbf{1}_X]^{\vee}.$$

Our main duality assumption will be that $\delta_{(X,\rho)}$ is a linear isomorphism for any (X,ρ) . Under this assumption we may define a linear morphism

$$f_* \colon [\mathbf{1}_Y, f^* \rho] \to [\mathbf{1}_X, \rho]$$

as the composition

$$[\mathbf{1}_Y, f^*\rho] \xrightarrow{\delta_{(Y, f^*\rho)}} [f^*\rho, \mathbf{1}_Y]^{\vee} \xrightarrow{(f^*)^{\vee}} [\rho, \mathbf{1}_X]^{\vee} \xrightarrow{\delta_{(X, \rho)}^{-1}} [\mathbf{1}_X, \rho].$$

In other words, if $v \in [\mathbf{1}_Y, f^*\rho]$, the element $f_*(v) \in [\mathbf{1}_X, \rho]$ is defined by the equation

$$\int_X (w\circ f_*(v))d\mu(x) = \int_Y ((f^*w)\circ v)d\mu(y)$$

for any $w \in [\rho, \mathbf{1}_X]$. Each such w can be uniquely written as a sum of elements w_x vanishing outside the isomorphism class of $x \in X$, for all such x. For such a w_x the above equation becomes

$$\frac{w_x \circ f_*(v)}{|\operatorname{Aut}(x)|} = \sum_{f([u])=[x]} \frac{(f^*w_x) \circ v}{|\operatorname{Aut}(y)|}.$$

Similarly, v can be uniquely written as a sum of elements v_y with nontrivial image only in the isomorphism class of $y \in Y$, i. e. $v_{y'}(1) = 0 \in \rho(f(y'))$ unless $y' \in [y]$. Choosing such a v_y with f(y) = x we get

$$\frac{w_x \circ f_*(v_y)}{|\operatorname{Aut}(x)|} = \frac{w_x \circ v_y}{|\operatorname{Aut}(y)|},$$

where we used the fact that, as $v \in [\mathbf{1}_Y, f^*\rho]$ and f(y) = x, the source of w_x coincides with the target of v_y and $(f^*w_x) \circ v_y = w_x \circ v_y$. As this has to be true for any w_x , we finally find

$$f_*(v_y) = \frac{|\operatorname{Aut}(x)|}{|\operatorname{Aut}(y)|} v_y,$$

for any v_y concentrated on y, with f(y) = x. From this we get the general formula

$$(f_*(v))_x = |\operatorname{Aut}(x)| \sum_{f([y])=[x]} \frac{v_y}{|\operatorname{Aut}(y)|}.$$

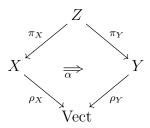
We can now define our wannabe functor

$$Sum_1: Fam_1(Vect) \rightarrow Vect$$

on objects as

$$\operatorname{Sum}_1(X,\rho) = [\mathbf{1}_X, \rho]$$

and on a morphism



as the composition

$$[\mathbf{1}_X,\rho_X] \xrightarrow{\pi_X^*} [\mathbf{1}_Z,\pi_X^*\rho_X] \xrightarrow{\alpha \circ -} [\mathbf{1}_Z,\pi_Y^*\rho_Y] \xrightarrow{\pi_{Y*}} [\mathbf{1}_Y,\rho_Y].$$

Remark 1.4. Before giving a more explicit expression of the above morphism, let us notice that $[\mathbf{1}_X, \rho]$ is a model for the limit of the functor $\rho \colon X \to \text{Vect}$, in accordance with the prescrition in [?]. Also, notice that the morphism associated to the span $X \leftarrow Z \to Y$ together with the natural transformation α has the form "pull-compose-push", and so it is an instance of a Fourier-Mukai-type transform.

Let us now give an explicit description of the functor Sum_1 . To begin with, notice that the datum of a functor $\rho\colon X\to\operatorname{Vect}$ is equivalent to the datum of a linear representation V_x of $\operatorname{Aut}_X(x)$ for every x in a set of representatives for the isomorphism classes of objects in X. So

$$[\mathbf{1}_X, \rho] = \bigoplus_{[x] \in \pi_0(X)} (V_x)^{\operatorname{Aut}_X(x)},$$

where V^G denotes the subspace of G-invariants for a linear G-representation on a vector space V. A linear map $[\mathbf{1}_X, \rho_X] \to [\mathbf{1}_Y, \rho_Y]$ can therefore be described by its "matrix coefficients" $(V_x)^{\operatorname{Aut}_X(x)} \to (W_y)^{\operatorname{Aut}_Y(y)}$ with [x] ranging in $\pi_0(X)$ and [y] ranging in $\pi_0(Y)$. The map $\pi_X^* \colon [\mathbf{1}_X, \rho_X] \to [\mathbf{1}_Z, \pi_X^* \rho_X]$ maps the invariant vector v_x in V_x to the tuple (v_x, v_x, \ldots, v_x) in $\bigoplus_{\pi_X([z])=[x]} V_x$. In this vector space, look at the direct sum over those [z] with $\pi_Y([z]) = [y]$. These are precisely those summands for which α_z is a linear morphism $V_x \to W_y$. The corresponding tuple $(\alpha_{z_1}(v_x), \alpha_{z_2}(v_x), \ldots, \alpha_{z_k}(v_x))$ is then the component of $(\alpha \circ \pi_X^*)(v_x)$ in $[\mathbf{1}_Z, \pi_Y^* \rho_Y]$ going into W_y via π_{Y^*} . As shown above, the mophism π_{Y^*} acts on this component by mapping it to

$$|\operatorname{Aut}(y)| \sum_{\substack{\pi_X([z])=[x]\\\pi_Y([z])=[y]}} \frac{\alpha_z(v_x)}{|\operatorname{Aut}(z)|}.$$

In other words, the matrix coefficient

$$(\Phi_{\alpha})_x^y \colon (V_x)^{\operatorname{Aut}_X(x)} \to (W_y)^{\operatorname{Aut}_Y(y)}$$

is

$$v_x \mapsto |\operatorname{Aut}(y)| \sum_{\substack{\pi_X([z])=[x]\\ \pi_Y([z])=[y]}} \frac{\alpha_z(v_x)}{|\operatorname{Aut}(z)|}.$$

The prefactor $|\operatorname{Aut}(y)|$ may appear odd, but it becomes transparent if we lower the y-index by using the pairing $\langle | \rangle_Y$. Namely, what we get this way is

$$(\Phi_{\alpha})_{xy} = \int_{Z_{x,y}} \alpha_z d\mu(z),$$

where $Z_{x,y}$ is the groupoid given by the (homotopy) fiber of Z over the point (x,y) of $X \times Y$. This exhibits the "propagator" $(\Phi_{\alpha})_{xy}$ as the "sum of α over the histories z going from x to y", and so as a discrete version of the Feynman path integral expression for propagators in quantum field theory.