YOU CAN CONSTRUCT G-COMMUTATIVE ALGEBRAS ONE NORM AT A TIME

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Abstract. We define the category of G-operads and the hierarchy of *generalized $\mathcal{N}_\infty$-operads*, which are G-suboperads of $\mathrm{Comm}_G^{\otimes}$. We exhibit an isomorphism between the category of generalized $\mathcal{N}_\infty$-operads and the self-join poset

$$\mathrm{Op}_G^{GN\infty} \simeq \mathrm{Ind}-\mathrm{Sys}_G \star \mathrm{Ind}-\mathrm{Sys}_G,$$

where $\mathrm{Ind}-\mathrm{Sys}_G$ is the poset of *indexing systems* in G. This recognizes generalized $\mathcal{N}_\infty$-operads as parameterizing *some commutative multiplicative transfers and possibly a commutative multiplication*. Indeed, their algerbas in semiadditive Cartesian categories are incomplete Mackey functors and their algebras in Mackey functors recover incomplete Tambara functors when they are N_∞ *operads*, i.e. when they contain $\mathbb{E}_\infty$.

After this, we discuss some in-progress research. Namely, we construct a *Boardman-Vogt tensor product* of G-operads and demonstrate that tensor products of genereralized $\mathcal{N}_\infty$ operads correspond with joins in $\mathrm{Ind}-\mathrm{Sys}_G \star \mathrm{Ind}-\mathrm{Sys}_G$ i.e. there is an $\mathcal{N}_{(I \vee J)\infty}$-monoidal equivalence

$$\mathbf{Alg}_{\mathcal{N}_{I\infty}} \mathbf{Alg}_{\mathcal{N}_{J\infty}} \mathcal{C} \simeq \mathbf{Alg}_{\mathcal{N}_{(I\vee J)\infty}} \mathcal{C}$$

for all $\mathcal{N}_{(I\vee J)\infty}$-monoidal categories $\mathcal{C}$, allowing G-commutative structures to be constructed "one norm at a time."

Foreword. The following are notes prepared for a casual talk in the zygotop seminar concerning research which is currently in-progress cite . The reader should read with the understanding that they are particularly casual error-prone, as the non-cited results herein amount to the communication of a pre-draft of a paper in a casual setting.

The reader should implicitly insert the text $\infty-$ before the words operad and category throughout the following text.

1. Introduction

In [Dre71], the concept of a *Mackey functor* was introduced; this structure was described as consisting of functors $M_I : \mathcal{O}_G \to \mathbf{Mod}_R$ and $M_R : \mathcal{O}_G^{\mathrm{op}} \to \mathbf{Mod}_R$ which agree on $\mathcal{O}_G^{\simeq}$ and satisfying the *double coset formula*

$$R_J^H I_K^H = \prod_{x \in [J \backslash H/K]} I^J_{J \cap xKx^{-1}} \cdot \mathrm{conj}_X R_{x^{-1}Jx \cap K}$$

for all $J, K \subset H$, where $R_J^K := M_R(G/J \to G/K)$ and similar for I. The ur-example of this is the assignment $H \mapsto \mathbf{Rep}_H$ with covariant functoriality Ind and contravariant functoriality Res. This was repackaged and generalized into the modern definition of the *category of $\mathcal{C}$-valued G-Mackey functors*

$$\mathcal{M}_G(\mathcal{C}) := \mathrm{Fun}^{\times}(\mathrm{Span}(\mathbb{F}_G), \mathcal{C}),$$

where $\mathbb{F}_G$ denotes the category of finite G-sets.

In parallel, the concept of *transfer maps in group cohomology* was being developed in **[Evens]**, later lifted to genuine equivariant cohomology in **[Greenlees]**, and finally developed as a functor

$$N_H^G : \mathrm{Sp}_H \to \mathrm{Sp}_G$$

in [HHR16], which played a crucial role in the solution to the Kervaire invariant one problem. These were noted in [HH16] to satisfy the conditions of a *Symmetric monoidal Mackey functor*, a notion they distinguished from their notion of *G-symmetric monoidal categories* due to coherence issues.

In the broad program announced in [Bar+16], the correct notion of *G-symmetric monoidal G-∞-categories* (henceforth G-symmetric monoidal categories) was introduced:

Definition 1.1. Let $\mathcal{C}$ have finite products. Then, the category of G-commutative monoids in $\mathcal{C}$ is

$$\mathrm{CMon}_G(\mathcal{C}) := \mathcal{M}_G(\mathcal{C}).$$

The category of G-symmetric monoidal categories is $\mathrm{CMon}_G(\mathbf{Cat})$.

We similarly define the *category of small G-categories* as

$$\mathbf{Cat}_G := \mathrm{Fun}(\mathcal{O}_G^{\mathrm{op}}, \mathbf{Cat}) \simeq \mathbf{Cat}^{\mathrm{cocart}}_{/\mathcal{O}_G^{\mathrm{op}}},$$

where the equivalence is the *straightening-unstraightening construction* of [HTT]. We may informally summarize the structure of a G-symmetric monoidal category $\mathcal{C}^\otimes \in \mathrm{CMon}_G(\mathbf{Cat})$ as consisting of, for every conjugacy class (H) of G, a category with Weyl group action $\mathcal{C}_H \in \mathbf{Cat}^{BW_GH}$, as well as functors

$$\otimes_H^2 : \mathcal{C}_H^2 \to \mathcal{C}_H,$$
$$N_K^H : \mathcal{C}_K \to \mathcal{C}_H,$$
$$\mathrm{Res}_K^H : \mathcal{C}_H \to \mathcal{C}_K$$

for all subconjugacy classes (K) of (H), which are associative, commutative, unital, and compatible with each other and the Weyl group action, together with coherence. The maps Res encode an underlying G-category $\mathcal{C}$ of $\mathcal{C}^\otimes$, and N_K^H is pronounced "the norm from K to H."

Given $\mathcal{C}^\otimes$ a G-symmetric monoidal category, we may informally define a *G-commutative monoid* to be a tuple of objects $(X_H)_{H \in \mathcal{O}_G} \in \prod_{H \in \mathcal{O}_G} \mathcal{C}_H$ satisfying

$$X_H \simeq \mathrm{Res}_H^G X_G$$

together with structure maps

$$\mu_H^2 : X_H^{\otimes 2} \to X_H$$
$$\mathrm{tr}_K^H : N_H^K X_K \to X_H,$$

for all $H \subset K$, together with associativity, commutativity, unitality, and coherence data. We may intuitively view these data as altogether specifying that these structure maps jointly construct a contractible space of maps

$$X^{\otimes S} \to X_H$$

for all finite H-sets $S \in \mathbb{F}_H$, where

$$X^{\otimes S} := \bigotimes_{H/K \in \mathrm{Orb}(S)} N_K^H X_K.$$

The map tr_K^H is pronounced "the transfer from K to $H3$." When $\mathcal{C}^\otimes = \mathcal{M}_G(\mathcal{C})^\otimes$ with the *HHR norm G-symmetric monoidal structure* of [HH16], these are called *G-Tambara functors valued in $\mathcal{C}$*.

This talk concerns various relaxations of the notion of G-commutative algebras. Namely, we will define a symmetric monoidal closed category Op_G of *(colored) G-operads*, whose internal hom $\underline{\mathbf{Alg}}_{\mathcal{O}}(\mathcal{C})^\otimes$ is called the *operad of algebras under pointwise tensors*, and whose tensor product is called the *Boardman-Vogt tensor product*.

A particular example will define *$\mathcal{N}_\infty$ operads*, which interpolate between $\mathbb{E}_\infty$ and the G-operad Comm_G which encodes G-commutative algebras by adding a subset of the transfers parameterized by Comm_G:

Definition 1.2. A *G-transfer system* is a core-preserving wide subcategory $\mathcal{O}_G^{\simeq} \subset T \subset \mathcal{O}_G$ which is closed under base change, i.e. for any diagram in $\mathcal{O}_G$

$$\begin{tikzcd} U \arrow[r] \arrow[d, "\alpha'"] & V \arrow[d, "\alpha"] \\ U' \arrow[r] & V' \end{tikzcd}$$

with $U \hookrightarrow V' \times_{U'} V$ a summand inclusion (pullback taken in $\mathbb{F}_G$) and $\alpha \in T$, we have $\alpha' \in T$.

An *indexing system* is a subcategory $I \subset \underline{\mathbb{F}}_G$ induced by a transfer system under taking coproducts. A *generalized indexing system* is a core-preserving subcategory $I \subset \underline{\mathbb{F}}_G$ which is either an indexing system or is attained by one by removing all non-isomorphisms of trivial G-sets. The poset of indexing systems under inclusion is denoted $\mathrm{Ind}-\mathrm{Sys}_G$, and the poset of generalized indexing systems is denoted .

It is not hard to see that there is an equivalence of posets

$$\widehat{\mathrm{Ind}-\mathrm{Sys}}_G \simeq \mathrm{Ind}-\mathrm{Sys}_G \star \mathrm{Ind}-\mathrm{Sys}_G,$$

and in particular, generalized indexing systems decompose into two different join-stable copies of indexing systems, depending on whether maps of trivial G-sets are included.

Given a generalized indexing system I, we will construct an operad called $\mathcal{N}_{I\infty}^{\otimes}$ encoding precisely the maps tr_K^H such that $K \hookrightarrow H$ is in I, as well as encoding the map μ_H if and only if I is an indexing system. The main theorem of this talk characterizes the tensor products of generalized $\mathcal{N}_\infty$ operads.

Theorem A. *There is a fully faithful and symmetric monoidal inclusion*

$$\mathcal{N}_{(-)\infty}^{\otimes} : \widehat{\mathrm{Ind}-\mathrm{Sys}}_G^{\amalg} \hookrightarrow \mathrm{Op}_G^{\otimes}$$

whose image consists of the suboperads of Comm_G*, and when restricted to the indexing systems has image consisting of operads* $\mathcal{O}$ *possessing diagrams* $\mathbb{E}_\infty \subset \mathcal{O} \subset \mathrm{Comm}_G$*. In particular, for* $\mathcal{C}$ *an* $\mathcal{N}_{(I\vee J)\infty}$*-monoidal category, there is a canonical* $\mathcal{N}_{(I\vee J)\infty}$*-monoidal equivalence*

$$\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{N}_{I\infty}} \underline{\mathbf{Alg}}^{\otimes}_{\mathcal{N}_{J\infty}} \mathcal{C} \simeq \underline{\mathbf{Alg}}^{\otimes}_{\mathcal{N}_{(I\vee J)\infty}} \mathcal{C}.$$

We say an inclusion of subgroup $H \subset K$ is *atomic* if it is proper and there exist no chains of proper subgroup inclusions $H \subset J \subset K$. More generally, we say that a conjugacy class $(H) \in \mathrm{Conj}(G)$ is an *atomic subclass* of (K) if there exists an atomic inclusion $\tilde{H} \subset \tilde{K}$ with $\tilde{H} \in (H)$ and $\tilde{K} \in (K)$, and we say that (K) is atomic if the canonical inclusion $1 \hookrightarrow K$ is atomic.

Given $(H) \subset (K)$ an atomic subclass, we refer to the $\mathcal{N}^\infty$-operad corresponding to the minimal index system containing the inclusion $H \hookrightarrow K$ as $\mathcal{N}^\infty(H, K)$. When $(H) = (1)$, we instead simply write $\mathcal{N}^\infty(K)$.

Corollary B. *Let* $1 = G_n \subset G_{n-1} \subset \cdots \subset G_0 = G$ *be a maximal subgroup series of a finite group, and let* $\mathcal{C}$ *be a* G*-symmetric monoidal category. Then, there exists a canonical* G*-symmetric monoidal equivalence*

$$\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{N}^\infty(G_1,G_0)} \cdots \underline{\mathbf{Alg}}^{\otimes}_{\mathcal{N}^\infty(G_n,G_{n-1})} \mathcal{C} \simeq \mathrm{CAlg}_G \mathcal{C}.$$

Furthermore, if $G \simeq H \times J$*, then*

$$\underline{\mathrm{CAlg}}^{\otimes}_{H} \underline{\mathrm{CAlg}}^{\otimes}_{J} \mathcal{C} \simeq \underline{\mathrm{CAlg}}^{\otimes}_{G} \mathcal{C}.$$

Remark. One may worry about the comparison between models for G-operads, as our notion of N_∞-operads is ostensibly embedded deep within the world of G-∞-operads, which are not known to be equivalent to the ∞-category presented by the graph model structure or by genuine G operads.

However, some work has been done to simplify the story of N_∞ operads in the model story; in particular, by [Rub21, Thm 2.16, 3.6], the full ∞-category of the ∞-category of *genuine* G-operads is equivalent to $\mathrm{Ind}-\mathrm{Sys}_G$ via a functor A which sits in a commutative diagram

$$\begin{tikzcd}
\mathrm{Op}_G^{\mathrm{gen},N\infty} \arrow[r, "N|_{N\infty}"] \arrow[dr, "A"'] & \mathrm{Op}_G^{N\infty} \arrow[d, "A"] \\
 & \mathrm{Ind}-\mathrm{Sys}_G
\end{tikzcd}$$

where we use that the functor N of [BP21] is canonically ∞-categorical when restricted to full subcategores of $\mathrm{Op}_G^{\mathrm{gen}}$ which happen to be 1-categories and map to a 1-subcategory of Op_G. Both functors named A are equivalences (c.f. **??**Ex 2.4.7]Nardin), and hence $N|_{N\infty}$ is an equivalence.

2. The ideas

2.1. **Fibrous patterns.** In order to precisely define I-operads, the most efficient way will be to go through the technology of *algebraic patterns*, a concept first defined by German mathematician Honyi Chu and the Norwegian mathematician Rune Haugseng, who generally referred to them using the letter $\mathcal{O}$.

Definition 2.1. An *algebraic pattern* is an ∞-category $\mathscr{O}$, together with a factorization system $(\mathscr{O}^{\mathrm{int}}, \mathscr{O}^{\mathrm{act}})$ of $\mathscr{O}$ and a full subcategory $\mathscr{O}^{\mathrm{el}} \subset \mathscr{O}^{\mathrm{int}}$. The *category of algebraic patterns* is the full subcategory

$$\mathrm{AlgPatt} \subset \mathrm{Fun}(D, \mathbf{Cat})$$

spanned by algebraic patterns, where $D := \bullet \to \bullet \to \bullet \leftarrow \bullet$.

Maps in $\mathscr{O}^{\mathrm{int}}$ and $\mathscr{O}^{\mathrm{act}}$ are pronounced *inert and active maps*, and objects of $\mathscr{O}^{\mathrm{el}}$ are pronounced *elementary objects*. For instance, $\mathbb{F}_*$, together with its inert and active maps as defined in [HA, § 2] and elementary objects $\{\langle 1 \rangle\}$ determines an algebraic pattern. In analogy with [HA, § 2], we will use these to develop a notion of operads, called *fibrous patterns*.

Definition 2.2. Let $\mathscr{O}$ be an algebraic pattern. A *fibrous $\mathscr{O}$-pattern* is a map of algebraic patterns $\pi : \mathcal{O} \to \mathscr{O}$ such that

(1) $\mathcal{O}$ has π-cocartesian lifts for inert morphisms of $\mathscr{O}$,
(2) (Segal condition for colors) For every active morphism $\omega : V_0 \to V_1$ in $\mathscr{O}$, the functor

$$\mathcal{K}_{V_0}^{\simeq} \to \lim_{\alpha \in \mathscr{O}^{\mathrm{el}}_{V_1/}} \mathcal{O}^{\simeq}_{\omega_{\alpha,!}V_1}$$

induced by cocartesian transport along ω_α is an equivalence, where $\omega_{(-)} : \mathscr{O}^{\mathrm{el}}_{Y/} \to \mathscr{O}^{\mathrm{int}}_{X/}$ is the inert morphism appearing in the inert-active factorization of $\alpha \circ \omega$, and
(3) (Segal condition for multimorphism) for every active morphism $\omega : V_1 \to V_2$ in $\mathscr{O}$ and all objects $X_i \in \mathcal{O}_{\mathscr{O}_{V_i}}$, the commutative square

$$\begin{tikzcd}
\mathrm{Map}_{\mathcal{O}}(X_0, X_1) \arrow[r] \arrow[d] & \lim_{\alpha \in \mathscr{O}^{\mathrm{el}}_{V_1/}} \mathrm{Map}_{\mathcal{O}}(X_0, \omega_{\alpha,!}X_1) \arrow[d] \\
\mathrm{Map}_{\mathscr{O}}(V_0, V_1) \arrow[r] & \lim_{\alpha \in \mathscr{O}^{\mathrm{el}}_{O_1/}} \mathrm{Map}_{\mathscr{O}}(O_0, \omega_{\alpha,!}O_1)
\end{tikzcd}$$

is cartesian.

A fibrous $\mathscr{O}$-pattern $\pi : \mathcal{C} \to \mathscr{O}$ is a *Segal $\mathscr{O}$-category* if π is a cocartesian fibration. The category of fibrous $\mathscr{O}$-patterns is the full subcategory

$$\mathrm{Fbrs}(\mathscr{O}) \subset \mathrm{AlgPatt}_{/\mathscr{O}}$$

spanned by fibrous patterns, and the category of Segal $\mathscr{O}$-∞-category is the full subcategory of

$$\mathrm{Seg}_{\mathscr{O}}(\mathbf{Cat}) \subset \mathrm{Fbrs}(\mathscr{O}) \times_{\mathbf{Cat}_{/\mathscr{O}}} \mathbf{Cat}^{\mathrm{cocart}}_{/\mathscr{O}}$$

spanned by Segal $\mathcal{O}$-categories.

We state one technical lemma:

Lemma 2.3. *All of the inclusions*

$$\mathrm{Seg}(\mathscr{O}) \to \mathrm{Fbrs}(\mathscr{O}) \hookrightarrow \mathrm{AlgPatt}_{/\mathscr{O}} \to \mathbf{Cat}_{/\mathscr{O}} \to \mathbf{Cat}$$

have left adjoints; in particular, the full subcategory $\mathrm{Fbrs}(\mathscr{O}) \subset \mathrm{AlgPatt}_{/base}$ *is localizing.*

We refer to the left adjoint $\mathrm{Env} : \mathrm{Fbrs}(\mathscr{O}) \to \mathrm{Seg}(\mathscr{O})$ as the *Segal envelope*, and we use it analogously to the *symmetric monoidal envelope*, reducing the question of characterizing maps of fibrous patterns into Segal $\mathscr{O}$-categories into simply a question of characterizing maps of Segal $\mathscr{O}$-categories, which is much simpler.

Example 2.4:

Definition 2.5. Given the data of $\mathcal{X}$ a category, $\mathcal{X}_b, \mathcal{X}_f$ wide subcategories, and $\mathcal{X}_0 \subset \mathcal{X}_b$ a full subcategory, we define the *span pattern* $\mathrm{Span}_{b,f}(\mathcal{X}; \mathcal{X}_0)$ to have:

- underlying category $\mathrm{Span}_{b,f}(\mathcal{X})$ whose objects are objects in $\mathcal{X}$ and whose morphisms $X \to Z$ are spans

$$X \xleftarrow{B} Y \xrightarrow{F} Z$$

with $B \in \mathcal{X}_b$ and $F \in \mathcal{X}_f$.
- inert morphisms $\mathcal{X}_b^{\mathrm{op}} \subset \mathrm{Span}(\mathcal{X})$.
- active morphisms $\mathcal{X}_f \subset \mathrm{Span}(\mathcal{X})$.
- Elementary objects $\mathcal{X}_0^{\mathrm{el}} \subset \mathcal{X}_b^{\mathrm{op}}$.

Then, for instance we have the following:

Theorem 2.6 ([BHS22]). *Pullback along the inclusion $\mathbb{F}_* \hookrightarrow \mathrm{Span}(\mathbb{F})$ induces an equivalence on the categories of fibrous patterns and Segal categories.*

2.2. **G-operads and $\mathcal{I}$-operads.** There is an adjunction

$$\mathrm{Tot} : \mathbf{Cat}_G \rightleftarrows \mathbf{Cat} : \mathrm{CoFr}^G$$

where Tot takes the total category of a cocartesian fibration and $\mathrm{CoFr}^G(\mathcal{C})$ is classified by functor categories

$$\mathrm{CoFr}^G(\mathcal{C})_H := \mathrm{Fun}(\mathcal{O}_H^{\mathrm{op}}, \mathcal{C})$$

with functoriality dictated by pullback. In particular, the *G-category of small G-categories* $\underline{\mathbf{Cat}}_G := \mathrm{CoFr}^G(\mathcal{C})$ has G-fixed points given by **Cat**.

Remark. Elmendorf's theorem may be reinterpreted in this language as the statement that the *G-category of G-spaces* $\mathcal{S}_G$ is cofreely generated by $\mathcal{S}$.

Let $\underline{\mathbb{F}}_G := \mathrm{CoFr}^G(\mathbb{F})$ and let $\underline{\mathbb{F}}_{G,*} := \mathrm{CoFr}^G(\mathbb{F}_*)$. Then, there is an equivariant lift of ref :

Theorem 2.7 ([BHS22]). *Pullback along the composition $\underline{\mathbb{F}}_{G,*} \hookrightarrow \mathrm{Span}(\mathrm{Tot}\underline{\mathbb{F}}_G) \xrightarrow{U} \mathrm{Span}(\mathbb{F}_G)$ induces an equivalence on the categories of fibrous patterns and Segal categories, where $\mathbb{F}_G$ is the category of G-sets.*

Definition 2.8. The *category of G-operads* is the category of fibrous patterns

$$\mathrm{Op}_G := \mathrm{Fbrs}(\mathrm{Span}(\mathbb{F}_G)).$$

The following proposition is an exercise in category theory which was carried out in [BHS22, § 5.2].

Proposition 2.9. *An identity-on-objects functor $\pi : \mathcal{O} \to \mathrm{Span}(\mathbb{F}_G)$ is a G-operad if and only if it satisfies the following conditions:*

(1) $\mathcal{O}$ has π-cocartesian lifts for inert morphisms of $\mathrm{Span}(\mathbb{F}_G)$.
(2) For every map of G-sets $S \to T$, the inert morphisms $\{U \leftarrow T \mid U \in \mathrm{Orb}(T)\}$ induce equivalences

$$\mathrm{Map}_{\mathcal{O}}(S, T) \simeq \prod_{U \in \mathrm{Orb}(T)} \mathrm{Map}_{\mathcal{O}}(S, U).$$

Furthermore, a cocartesian fibration $\pi : \mathcal{O} \to \mathrm{Span}(\mathbb{F}_G)$ is a Segal $\mathrm{Span}(\mathbb{F}_G)$-category if and only if it unstraightens to a G-symmetric monoidal category.

We may further reorganize this through the following elementary lemma about G-sets.

Lemma 2.10. *The assignment $\varphi : T \mapsto \mathrm{Ind}_H^G T \to G/H$ underlies an equivalence of categories*

$$\mathbb{F}_H \simeq (\mathbb{F}_G)_{/G/H}.$$

Hence we have a forgetful functor

$$\mathcal{O}(-) : \mathrm{Op}_G^{\mathrm{one-object}} \to \mathrm{Fun}(\mathrm{Tot}\underline{\mathbb{F}}_G^{\simeq}, \mathcal{S})$$

Given $S \in \mathbb{F}_H$, we refer to $\mathcal{O}(S)$ as the *space of S-ary operations*. We further analyze this functor in ref , proving e.g. that it is conservative.

An early observation about genuine equivariant homotopy coherent algebraic structures is that the structure of transfers *does not come canonically* from an $\mathbb{E}_\infty$-structure; that is, $\mathbb{E}_\infty \in \mathrm{Op}_G$ is not terminal. The failure of $\mathbb{E}_\infty$ to be terminal is parameterized by the category of *generalized N^∞-operads*:

Definition 2.11. Write $\mathrm{Comm}_G^{\otimes} := \left(\mathrm{Span}(\mathbb{F}_G) = \mathrm{Span}(\mathbb{F}_G)\right)$ for the terminal G-operad. A G-operad $\mathcal{O}^{\otimes}$ is a *generalized* $\mathcal{N}^{\infty}$*-operad* if the unique morphism $\mathcal{O}^{\otimes} \to \mathrm{Comm}_G^{\otimes}$ is a monomorphism, i.e. it has one object and

$$\mathcal{O}(S) \in \{*, \varnothing\}$$

for all $S \in \mathbb{F}_H$.

A generalized $\mathcal{N}^{\infty}$ operad $\mathcal{N}_{\infty I}$ is an N^{∞} *operad* if it admits a map

$$\mathbb{E}_{\infty} \to \mathcal{O}^{\otimes},$$

i.e. $\mathcal{O}(S) \simeq *$ whenever $S \in \mathbb{F}_H$ has trivial H-action.

Write $\mathrm{Op}_G^{GN\infty}$ for the full subcategory consisting of generalized $\mathcal{N}_{\infty}$-operads. The following proposition is an exercise in category theory, and establishes that a map to an $\mathcal{N}_{\infty}$ operad is a *property*, not a structure.

Proposition 2.12. *Given $\mathcal{N}_{I\infty} \in \mathrm{Op}_G^{GN\infty}$ a generalized $\mathcal{N}_{\infty}$ operad, the forgetful functor*

$$\mathrm{Op}_{G,/\mathcal{N}_{I\infty}} \to \mathrm{Op}_G$$

is fully faithful.

Proof idea. It is equivalent to prove that $\mathrm{Map}(\mathcal{O}, \mathcal{N}_{I\infty}) \in \{*, \varnothing\}$ for all $\mathcal{O} \in \mathrm{Op}_G$ In fact, there is a localizing (1-) subcategory $N : \mathrm{Op}_{1,G} \hookrightarrow \mathrm{Op}_G$ consisting of operads whose structure spaces are discrete, and whose localization functor $h : \mathrm{Op}_G \to \mathrm{Op}_{1,G}$ takes π_0 of the structure spaces. $\mathcal{N}_{I\infty}$ evidently lies in $\mathrm{Op}_{1,G}$, so we have

$$\mathrm{Map}_{\mathrm{Op}_G}(\mathcal{O}, \mathcal{N}_{I\infty}) \simeq \mathrm{Hom}_{\mathrm{Op}_{1,G}}(h\mathcal{O}, \mathcal{N}_{I\infty}).$$

Hence it suffices to check that the latter set is empty or contractible. This is easy to see in $\mathrm{Op}_{1,G}$, since $\mathrm{Hom}(-, *)$ and $\mathrm{Hom}(-, \varnothing)$ are always either empty or contractible. □

In particular, this implies that $\mathrm{Op}_G^{GN\infty}$ is a poset, so we'd like to identify this poset. There is a functor

$$A : \mathrm{Op}_G \to \widehat{\mathrm{Ind} - \mathrm{Sys}}_G$$

called the *admissible sets* with value over G/H given by

$$A(\mathcal{O})_{/(G/H)} := \left\{S \to G/H \mid \pi_{\mathcal{O}}^{-1}(S \to G/H) \neq \varnothing\right\}$$

and extended to general G-sets by coproducts. The following proposition is an exercise in category theory (see [NS22, Ex 2.4.7], or the original references [BH15; GW18; Rub21]):

Proposition 2.13. *The restricted functor*

$$A : \mathrm{Op}_G^{GN\infty} \to \widehat{\mathrm{Ind} - \mathrm{Sys}}_G$$

is an equivalence of categories.

We denote by $\mathcal{N}_{(-)\infty}$ the composite functor

$$\mathcal{N}_{(-)\infty} : \widehat{\mathrm{Ind} - \mathrm{Sys}}_G \xrightarrow{A^{-1}} \mathrm{Op}_G^{GN\infty} \hookrightarrow \mathrm{Op}_G$$

Using this, we finally define *I-operads*.

Definition 2.14. Let I be a generalized indexing system. Then, the *category of I-operads* is the slice category

$$\mathrm{Op}_I := \mathrm{Op}_{G,/\mathcal{N}_{\infty I}^{\otimes}}.$$

Given $\mathcal{O}^{\otimes}, \mathcal{P}^{\otimes} \in \mathrm{Op}_I$, the *category of $\mathcal{O}$-algebras in $\mathcal{P}$* is the full subcategory

$$\mathbf{Alg}_{\mathcal{O}}(\mathcal{C}) \subset \mathrm{Fun}_{/\mathcal{N}_{\infty I}^{\otimes}}(\mathcal{O}^{\otimes}, \mathcal{C}^{\otimes})$$

spanned by maps of $\mathcal{I}$-operads.

Remark. The notation $\mathbf{Alg}_{\mathcal{O}}(\mathcal{C})$ does not include $\mathcal{I}$. This presents no problem; indeed, by proposition 2.12, the categories of $\mathcal{O}$-algebras in $\mathcal{P}$ considered over various indexing systems (including the terminal one, i.e. in G-operads) are canonically equivalent to one another.

A useful property of these are that G operads *fibered* over $\mathcal{O}^{\otimes}$ have an intrinsic description in terms of $\mathcal{O}$. We may state these in the language of fibrous patterns.

Proposition 2.15 (cite). *Let $\mathcal{O}$ be a fibrous $\mathscr{E}$-pattern. Then, the pushforward functor $\pi_! : \mathrm{AlgPatt}_{/\mathcal{O}} \to \mathrm{AlgPatt}_{/\mathscr{E}}$ preserves fibrous patterns, and the associated functor*

$$\pi_! : \mathrm{Fbrs}(\mathcal{O}) \to \mathrm{Fbrs}(\mathscr{E})_{/\mathcal{O}}$$

is an equivalence of categories.

In particular, the category of I-operads is covariantly functorial in I, and it possesses an intrinsic expression along the lines of ref .

Example 2.16:
Let $\mathcal{F} \subset \mathcal{O}_G$ be a *family*, i.e. a collection of subgroups of G closed under sub-conjugation. Then, $\mathcal{F} \cup \mathcal{O}_G^{\simeq}$ is a transfer system, and we denote by $\mathcal{I}_{\mathcal{F}}$ the corresponding indexing system.

Let V be a real orthogonal G-representation, let $\mathcal{F}_V$ is the family consisting of subgroups H such that $V^H \neq *$, and let $\mathcal{I}_V := \mathcal{I}_{\mathcal{F}_V}$. Then, there is an I_V-operad $\mathbb{E}_V$ of *little V-disks*, which may be informally understood to have

$$\pi_{\mathbb{E}_V}^{-1}(\mathrm{Ind}_H^G T \to G/H) := \mathrm{Conf}_H(T, V)$$

the space of H-equivariant embeddings of $T \hookrightarrow V$ (c.f. [Hor19]). These participate in *equivariant infinite loop space theory*, in the sense that there is an equivalence

$$\mathbf{Alg}_{\mathbb{E}_V}(\mathcal{S}_G) \simeq \{V - \textit{loop spaces}\}\,;$$

see Guillou-May for details.

2.3. **The BV tensor product.** By ref , the category of algebraic patterns has a cartesian monoidal structure.

Definition 2.17. The category of *symmetric monoidal algebraic patterns* is CMon(AlgPatt).

A symmetric monoidal structure on $\mathscr{E}$ endows on the slice category $\mathrm{AlgPatt}^{\otimes}_{/\mathscr{E}}$ a symmetric monoidal structure, which we may view as taking $\mathcal{O}, \mathcal{P}$ to the tensor product

$$\mathcal{O} \times \mathcal{P} \to \mathscr{E} \times \mathscr{E} \to \mathscr{E}.$$

Definition 2.18. The *Boardman-Vogt symmetric monoidal category of fibrous $\mathscr{E}$-patterns* is the localized symmetric monoidal structure

$$\mathrm{Fbrs}(\mathscr{E})^{\otimes} \leftrightarrows \mathrm{AlgPatt}^{\otimes}_{/\mathscr{E}}.$$

We may view the tensor product of fibrous $\mathscr{E}$-patterns as yielding the localized composite

$$\mathcal{O} \otimes \mathcal{P} := L_{\mathrm{Fbrs}}(\mathcal{O} \times \mathcal{P} \to \mathscr{E} \times \mathscr{E} \to \mathscr{E}).$$

Note that the category $\mathbb{F}_G$ has finite products, and any indexing system $\mathcal{I}$ is closed under products. In particular, this endows $i : \mathcal{N}^{\otimes}_{\mathcal{I}\infty} \to \mathrm{Span}(\mathbb{F}_G)$ with the structure of a map of symmetric monoidal algebraic patterns under the so it has a cartesian monoidal structure. By cite , the forgetful functor $\mathrm{Fbrs}(\mathcal{O}) \to \mathrm{Fbrs}(\mathscr{E})_{/\mathcal{O}}$ is an equivalence, so we may use this to define the BV tensor product of I-operads.

Definition 2.19. The *Boardman-Vogt symmetric monoidal category of I-operads* is

$$\mathrm{Op}^{\otimes}_{\mathcal{I}} := \mathrm{Fbrs}(\mathcal{N}_{\mathcal{I}\infty})$$

The following proposition is easy:

Proposition 2.20. *Given an inclusion $i : \mathcal{N}_{\mathcal{I}\infty} \hookrightarrow \mathcal{N}_{\mathcal{J}\infty}$, pushforward along i yields a functor*

$$i_! : \mathrm{Op}^{\otimes}_{\mathcal{I}} \to \mathrm{Op}^{\otimes}_{\mathcal{J}}$$

realizing $\mathrm{Op}_{\mathcal{I}}$ as a symmetric monoidal colocalizing subcategory of $\mathrm{Op}_{\mathcal{J}}$.

The verification of this comes down to the following fact:

Lemma 2.21. *Given $f : X \to Y$ a map of commutative algebra objects in C a symmetric monoidal, the associated functor $f_! : C_{/X} \to C_{/Y}$ lifts to a canonical symmetric monoidal functor between the slice symmetric monoidal categories.*

The BV tensor product satisfies a mapping out property; namely, we review in ref the construction due to [NS22, § 5.3] of the operad $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{P}}(\mathcal{Q})$, and we prove the following theorem.

Theorem 2.22. *There is a natural equivalence of operads*

$$\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{O}\otimes\mathcal{P}} Q \simeq \underline{\mathbf{Alg}}^{\otimes}_{\mathcal{O}} \underline{\mathbf{Alg}}^{\otimes}_{\mathcal{P}} Q$$

realizing $\mathbf{Alg}^{\otimes}_{\mathcal{P}}(-)$ *as an internal hom for the BV tensor product.*

2.4. **Summary of the argument.** We would like to construct an equivalence $\mathcal{N}_{I\infty} \otimes \mathcal{N}_{J\infty} \simeq \mathcal{N}_{(I\vee J)\infty}$. Let's begin with the special case $I \subset J$; in this case, we can say something stronger.

Proposition 2.23. *If $\mathcal{O}$ is a one-object G-operad, then the map $\mathcal{N}^{\infty}(I) \to \mathcal{N}^{\infty}(I) \otimes \mathcal{O}$ is an I-equivalence; in particular, $\mathcal{N}^{\infty}(I)$ is $\otimes$-idempotent.*

To prove this, we use [NS22, Cor 5.3.9]; in particular, they generalize [HA] to verify that any of the following conditions are true of $\mathbf{Alg}^{\otimes}_{\mathcal{N}^{\infty}(I)}(\mathcal{C})$, and we verify that the conditions are equivalent in ref .

Lemma 2.24. *The following are equivalent:*

(1) *The forgetful functor* $\mathrm{CAlg}_I(\mathcal{C}) \to \mathcal{C}$ *is an equivalence.*
(2) *For all one-object I-operads $\mathcal{O}$, the forgetful functor $\mathbf{Alg}^{\mathcal{O}}(\mathcal{C}) \to \mathcal{C}$ is an equivalence.*
(3) *The I-restricted operad is cocartesian*

Having proved this, we acquire a (unique) diagram

$$\begin{tikzcd}
\mathcal{N}_{I\infty} \arrow[dr] \arrow[drr] & & & \\
& \mathcal{N}_{I\infty} \otimes \mathcal{N}_{J\infty} \arrow[r, "\varphi"] & \mathcal{N}_{(I\vee J)\infty} \otimes \mathcal{N}_{(I\vee J)\infty} = \mathcal{N}_{(I\vee J)\infty} \\
\mathcal{N}_{J\infty} \arrow[ur] \arrow[urr] & & &
\end{tikzcd}$$

and we are tasked with proving that φ is an equivalence. An unfortunate fact is that the functor $U : \mathrm{Op}_{I\vee J} \to \mathrm{Op}_I \times \mathrm{Op}_J$ doesn't appear to be conservative in general. Our strategy will come down to trying *really hard* to make it conservative. We do so via the following two lemmas, proved as lemmas 3.5 and 3.7.

Lemma 2.25. *Denote by $i : I \cup J \subset I \vee J$ the (non-indexing system) union of subcategories. Then, the pullback*

$$\mathrm{Fbrs}(\mathrm{Span}(\mathcal{I} \cup \mathcal{J})) \to \mathrm{Op}_I \times \mathrm{Op}_J$$

is conservative. In particular, U reflects equivalences between $\mathcal{I} \vee \mathcal{J}$-operads in the image of $L_{\mathrm{Fbrs}} i_!$.

Lemma 2.26. *There is an equivalence $\mathcal{N}_{(I\vee J)\infty} \simeq L_{\mathrm{Fbrs}} i_! \,\mathrm{Span}(I \cup J)$.*

Proof of theorem A. By the above argument, it suffices to prove that φ is an equivalence; in fact, by lemmas 2.25 and 2.26 and symmetry it suffices to prove that the localized functor

$$\iota_J^* \mathcal{N}_{I\cap J\infty} \otimes \mathcal{N}_{J\infty} \to \iota_J^* \mathcal{N}_{I\vee J}$$

is an equivalence. But $\iota_J^* \mathcal{N}_{I\infty} \simeq \mathcal{N}_{I\cap J\infty}$, so the above is the inclusion $\mathcal{N}_{I\cap J\infty} \otimes \mathcal{N}_{J\infty} \to \mathcal{N}_{J\infty}$, which is an equivalence by proposition 2.23. ◻

3. Technical nonsense

3.1. **Passing to monads is conservative.** Our arguments will be reminiscent of [SY19, § 2.3-2.4]

Given $\mathcal{O} \to \mathscr{O}$ a fibrous pattern, we define the algebraic pattern

$$i : \mathscr{O}^{\mathrm{el}} \hookrightarrow \mathscr{O}$$

to have $\left(\mathscr{O}^{\mathrm{el}}\right)^{\mathrm{el}} = \left(\mathscr{O}^{\mathrm{el}}\right)^{\mathrm{int}} = \mathscr{O}^{\mathrm{el}} = \left(\mathscr{O}^{\mathrm{el}}\right)^{\mathrm{act}}$. Define $\underline{\mathbb{F}}_{\mathscr{O}} := \left(\mathrm{Env}_{\mathscr{O}} \mathscr{O}^{\mathrm{el}}\right)^{\mathrm{el}}$.

Lemma 3.1 (C.f. [SY19, Prop 2.3.6])**.** *Let $\mathrm{Fbrs}_{\bullet}(\mathscr{O})$ denote the full subcategory of fibrous patterns whose associated maps $\mathcal{O}^{\mathrm{el}} \to \mathscr{O}^{\mathrm{el}}$ are equivalences. Then, the functor*

$$i^* \mathrm{Env}_{\mathscr{O}} : \mathrm{Fbrs}_{\bullet}(\mathscr{O}) \to \mathrm{Fun}\left(\underline{\mathbb{F}}_{\mathscr{O}}, \mathcal{S}\right)$$

is conservative.

Proof. Just look at the Segal condition for fibrous patterns □

We now specialize to the case $\mathcal{I} = \mathrm{Span}(\mathbb{F}_G)$. Let $\mathcal{C}$ be a G-symmetric monoidal category, let $\mathcal{O} \in \mathrm{Op}_G$ be a G-operad, and let $X \in \mathbf{Alg}_{\mathcal{O}}(\mathcal{C})$ be an $\mathcal{O}$-algebra in $\mathcal{C}$.

Note that $\mathrm{Span}(\mathbb{F}_G)^{\mathrm{el}} \simeq \mathrm{triv}$; further, note that

$$\begin{aligned}\mathrm{Env}_{\mathrm{Span}(\mathbb{F}_G)}\mathrm{triv} &\simeq \mathcal{O}_G^{\mathrm{op}} \times_{\mathrm{Span}(\mathbb{F}_G)} \mathrm{Ar}_{\mathrm{act}}\, \mathrm{Span}(\mathbb{F}_G) \\ &\simeq \mathrm{Tot}\underline{\Sigma}_G,\end{aligned}$$

where $\underline{\Sigma}_G \simeq \mathrm{CoFr}^G$. Then, lemma 3.1 translates to the following:

Proposition 3.2. *The forgetful functor*

$$(-)_{\mathrm{sseq}} : \mathrm{Op}_G \to \mathrm{Fun}(\mathrm{Tot}\underline{\Sigma}_G, \mathcal{S})$$

sending $\mathcal{O}(S) := \pi_{\mathcal{O}}^{-1}(\mathrm{Ind}_H^G S \to G/H)$ for all $S \in \mathbb{F}_H$ is conservative.

Remark. The *genuine model structure* $\mathrm{Sym}_\bullet^G(\mathrm{sSet})$ of [BP22] exists and presents $\mathrm{Fun}(\mathrm{Tot}\underline{\Sigma}_G, \mathcal{S})$; the ∞-category of *Genuine G-operads* are then algebras over a monad on $\mathrm{Fun}(\mathrm{Tot}\underline{\Sigma}_G, \mathcal{S})$ which are explicitly defined in [BP21].

In this setting, lemma 3.1 amounts to a verification of one of the two Barr-Beck conditions expressing U as *monadic* (cf [HA, Thm 4.7.3.5]); if one can verify that U creates spit geometric realizations and characterize the associated monad along the lines of [BP21], then they may prove that one-object genuine G-operads are equivalent to one-object G-operads. The author hopes to explore this as a potential strategy for comparison results in the future.

We say that a G-operad $\mathcal{O}^\otimes$ is *reduced* if $\mathcal{O}(T) = *$ whenever T is empty or a transitive H set. Let $\mathcal{O}^\otimes$ be a reduced G-operad, $\mathcal{C}$ a G-symmetric monoidal category, and $X : \mathrm{triv}^\otimes \to \mathcal{C}^\otimes$ a G-object. Denote by $X_{\mathrm{sseq}} \in \mathrm{Fun}_G(\underline{\Sigma}_G, \mathcal{C})$ the functor of G-categories underlying the adjunct map of G-symmetric monoidal categories to X. We can use this to characterize the *monad* associated with an operad. Define distributivity, use [NS22, Prop 3.2.5].

Proposition 3.3. *Let $\mathcal{O}$ be a reduced G-operad and let $\mathcal{C}^\otimes$ be a distributive G-symmetric monoidal category. Then, the forgetful map $\underline{\mathbf{Alg}}_{\mathcal{O}}(\mathcal{C}) \to \mathcal{C}$ is monadic, and the associated monad $T_{\mathcal{O}}$ acts on $X \in \mathcal{C}$ as*

$$T_{\mathcal{O}} X := \mathrm{colim}\, X_{\mathrm{sseq}}.$$

In particular, we have

$$(T_{\mathcal{O}} X)^H \simeq \coprod_{\substack{J \supset K \subset H \\ S \in \mathbb{F}_J}} \left(\mathcal{O}(S) \otimes X^{\otimes\left(\mathrm{Ind}_K^H \mathrm{Res}_K^J S\right)} \right)_{h\, \mathrm{Aut}_J S},$$

where for all $S' \in \mathbb{F}_H$, we write

$$X^{\otimes S'} := \bigotimes_{U \in \mathrm{Orb}(S')} N_U^H X_U.$$

Suppose $\mathcal{C}$ is a finitely cocomplete Cartesian closed category, and let $\mathrm{CoFr}^G(\mathcal{C})$ be the G-category of G-coefficient systems valued in $\mathcal{C}$, and write $\mathcal{C}_G := \mathrm{CoFr}^G(\mathcal{C})^G \simeq \mathrm{Fun}(\mathcal{O}_G^{\mathrm{op}}, \mathcal{C})$. By [NS22, Prop 3.2.5] (noting that all colimits involved are finite), the G-Cartesian G-symmetric monoidal structure on $\mathrm{CoFr}^G(\mathcal{C})$ is distributive. In fact, there is an adjunction $\mathrm{triv} : \mathcal{C} \rightleftarrows \mathrm{CoFr}^G(\mathcal{C})^G = \mathrm{Fun}(\mathcal{O}_G^{\mathrm{op}}, \mathcal{C}) : F^G$, where triv is fully faithful and bicontinuous (indeed, it has a left adjoint given by F_G) and the diagram of forgetful functors

$$\begin{tikzcd} \mathbf{Alg}_{\mathcal{O}}(\mathrm{CoFr}^G(\mathcal{C}))^G \arrow[r, "\sim"] \arrow[d, "U^G"] & \mathrm{Seg}_{\mathcal{O}}(\mathcal{C}_G) \arrow[r, "F^G"] \arrow[d, "U"] & \mathrm{Seg}_{\mathcal{O}}(\mathcal{C}) \arrow[d, "U"] \\ \mathcal{C}_G \arrow[r, equal] & \mathcal{C}_G \arrow[r, "F^G"] & \mathcal{C} \end{tikzcd}$$

commutes for any G-operad $\mathcal{O}$. Taking left adjoints to this yields a commutative diagram of adjunctions, and noting that fixed points of G-adjunctions are adjunctions yields the following corollary in the case $\mathcal{C} = \mathcal{S}$.

Corollary 3.4. *Let $\mathcal{O}$ be a reduced G-operad. Then, the associated monad $T_{\mathcal{O},\mathcal{S}}$ acts on $X \in \mathcal{S}$ as*

$$T_{\mathcal{O},\mathcal{S}} X \simeq \left(T_{\mathcal{O},\mathcal{S}} X\right)^G \simeq \coprod_{\substack{J \supset H \\ S \in \mathbb{F}_J}} \left(\mathcal{O}(S) \times \mathrm{Ind}_e^{\mathrm{Ind}_K^G \mathrm{Res}_K^J S} X\right)_{h \mathrm{Aut}_J S}.$$

In particular, the functor $\mathbf{Alg}_{(-)}(\mathcal{S}) : \mathrm{Op}_G^{\mathrm{Red}} \to \mathbf{Cat}$ is conservative.

Proof. All but the final statement follow by the above analysis. Suppose $\varphi : \mathcal{O} \to \mathcal{P}$ induces an equivalence on $\mathbf{Alg}_{\mathcal{O}}(\mathcal{S}) \to \mathbf{Alg}_{\mathcal{P}}(\mathcal{S})$..

Then φ induces a natural equivalence $T_{\mathcal{O},\mathcal{S}} \implies T_{\mathcal{P},\mathcal{S}}$ respecting the summand decomposition in the above presentation. In particular, taking $K = \{e\}$, for all $S \in \mathbb{F}_J$, this induces an equivalence

$$\left(\mathcal{O}(S) \times \mathrm{Ind}_J^S X\right)_{h \mathrm{Aut}_J S}.$$

Choosing X a set with at least 2 points, we find that $n_S \cdot \mathcal{O}(S) \to n_S \cdot \mathcal{P}(S)$ is an equivalence for some $n_S > 0$ and all S; this implies that $\mathcal{O}(S) \to \mathcal{P}(S)$ is an equivalence for all S, i.e. φ_Σ is an equivalence. By lemma 3.1, this implies φ is an equivalence. □

The remainder of this subsection will be dedicated to proving proposition 3.3.

Proof of proposition 3.3. Monadicity is precisely [NS22, Cor 5.1.5] when $\mathcal{T} = \mathcal{O}_G$, so it suffices to compute the associated monad in this case. Note that $X_{\mathrm{sseq}}(S) \simeq \mathcal{O}(S) \otimes X^{\otimes S}$, so the computation of $(T_{\mathcal{O}} X)^H$ follows immediately from the statement $T_{\mathcal{O}} X \simeq \mathrm{colim}\, X_{\mathrm{sseq}}$, so it suffices to prove this statement.

By [NS22, Rem 4.3.6], the left adjoint $\mathrm{Fr} : \mathcal{C} \to \mathbf{Alg}_{\mathcal{O}}(\mathcal{C})$ is computed on X by G-operadic left Kan extension of the corresponding map $\mathrm{triv}^{\otimes} \xrightarrow{X} \mathcal{C}^{\otimes}$ along the canonical inclusion $\mathrm{triv}^{\otimes} \to \mathcal{O}^{\otimes}$; the underlying G-functor of this is computed by the G-left Kan extension

$$\begin{tikzcd}
\Sigma_G \arrow[r, equal] \arrow[d] & \mathrm{Env}_{\mathcal{O}} \mathrm{triv} \arrow[r, "X"] \arrow[d] \arrow[dr, phantom, "\Searrow"] & \mathcal{C} \\
*_G \arrow[r, equal] & \mathcal{O} \arrow[ur, dashed, "\mathrm{Fr}\, X"'] &
\end{tikzcd}$$

I.e. by the indexed colimit

$$T_{\mathcal{O}} X \simeq \mathrm{colim}\, X_{\mathrm{sseq}}.$$

□

3.2. **The conservativity lemmas.** We have two conservativity lemmas to prove. The first is easier:

Lemma 3.5. *Denote by $i : I \cup J \subset I \vee J$ the (non-indexing system) union of subcategories. Then, the pullback*

$$\mathrm{Fbrs}(\mathrm{Span}(\mathcal{I} \cup \mathcal{J})) \to \mathrm{Op}_I \times \mathrm{Op}_J$$

is conservative. In particular, U reflects equivalences between $\mathcal{I} \vee \mathcal{J}$-operads in the image of $L_{\mathrm{Fbrs}} i_!$.

Proof. Passing to the underlying symmetric sequences yields a diagram

$$\begin{tikzcd}
\mathrm{Fbrs}(\mathrm{Span}(I \cup J)) \arrow[r, "i^*"] \arrow[d, tail] & \mathrm{Op}_I \times \mathrm{Op}_J \arrow[d] \\
\mathrm{Fun}(I \cup J, \mathcal{S}) \arrow[r, tail] & \mathrm{Fun}(I, \mathcal{S}) \times \mathrm{Fun}(J, \mathcal{S})
\end{tikzcd}$$

The diagonal functor is a composite of two conservative arrows by **??**, so it is conservative, and hence i^* is conservative. □

The second will take a bit more work. Note that the Segal conditions for Segal Span$(I \cup J)$-categories are a *Union* of those of Segal Span(I)-categories and Segal Span(J)-categories. That is,

Lemma 3.6. *The following diagram of categories is cartesian:*

$$\begin{tikzcd} \mathrm{Seg}_{\mathrm{Span}(I\cup J)}(\mathcal{C}) \arrow[r] \arrow[d] & \mathrm{Seg}_{\mathrm{Span}(I)}(\mathcal{C}) \arrow[d] \\ \mathrm{Seg}_{\mathrm{Span}(J)}(\mathcal{C}) \arrow[r] & \mathrm{Seg}_{\mathrm{Span}(I\cap J)}(\mathcal{C}) \end{tikzcd}$$

In particular, all but the top left are simply categories of product preserving functors. We use this:

Lemma 3.7. *There is an equivalence $\mathcal{N}_{(I\vee J)\infty} \simeq L_{\mathrm{Fbrs}} i_! \,\mathrm{Span}(I \cup J)$.*

Proof. The functor $L_{\mathrm{Fbrs}} i_! \,\mathrm{Span}(I \cup J)$ is left adjoint to i^*, so it suffices by lemma to verify that the following square is cartesian:

$$\begin{tikzcd} \mathrm{Fun}^{\times}(\mathrm{Span}(I \vee J), \mathcal{S}) \arrow[r] \arrow[d] & \mathrm{Fun}^{\times}(\mathrm{Span}(I), \mathcal{S}) \arrow[d] \\ \mathrm{Fun}^{times}(\mathrm{Span}(J), \mathcal{S}) \arrow[r] & \mathrm{Fun}^{\times}(\mathrm{Span}(I \cap J, \mathcal{S}) \end{tikzcd}$$

The property that this square is cartesian is witnessed by the equivalence

$$\mathrm{Span}(I \vee J) \simeq \mathrm{Span}(I) \coprod_{\mathrm{Span}(I\cap J)} \mathrm{Span}(J),$$

with pushout taken in the category of Cartesian categories and product preserving functors. □

3.3. **The internal hom.** Let $F : \mathcal{O}^{\otimes} \times_G \mathcal{P}^{\otimes} \to \mathcal{E}^{\otimes}$ be a bifunctor of G-operads and let $\mathcal{C}^{\otimes} \to \mathcal{E}^{\otimes}$ be a functor of G-operads. The following construction was coined in [NS22, § 5.3]. $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{E},G}(\mathcal{O}; \mathcal{C})$ was constructed as follows:

Construction 3.8. Define $P : \mathcal{O}^{\otimes} \times_G \mathrm{Ar}(\mathcal{O}_G^{\mathrm{op}}) \to \mathcal{O}^{\otimes}$ by cocartesian pushforward. We have a diagram

$$\mathcal{O}^{\otimes} \xleftarrow{\pi} \mathcal{O}^{\otimes} \times_G \mathrm{Ar}(\mathcal{T}) \times_G \mathcal{P}^{\otimes} \xrightarrow{P\times \mathrm{id}} \mathcal{O}^{\otimes} \times_G \mathcal{P}^{\otimes} \xrightarrow{F} \mathcal{E}^{\otimes}.$$

and an associated push-pull adjunction

$$L_{\mathrm{Fbrs}} F_! (P \times \mathrm{id})_! \pi^* : \mathrm{Op}_{G,/\mathcal{O}} \rightleftarrows \mathrm{Op}_{G,/\mathcal{E}} : \pi_* (P \times \mathrm{id})^* F^*.$$

We verify that this adjunction exists in lemma 3.9. and we define $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{E}}(\mathcal{P}; \mathcal{C}) \to \mathcal{O}^{\otimes}$ to be $\pi_*(P \times \mathrm{id})^* F^*(\mathcal{C}^{\otimes} \to \mathcal{E}^{\otimes})$.

Lemma 3.9. *Let P, F, π be defined above. Then,*

(1) *π is a strong Segal morphism, and the pullback functor*

$$\pi_* : \mathbf{Cat}_{/\mathcal{O}^{\otimes}} \to \mathbf{Cat}_{/\mathcal{O}^{\otimes} \times_G \mathrm{Ar}(\mathcal{O}_G) \times_G \mathcal{P}^{\otimes}}$$

preserves fibrous patterns; hence $\pi_* : \mathrm{Fbrs}(\mathcal{O}^{\otimes}) \to \mathrm{Fbrs}(\mathcal{O}^{\otimes} \times_G \mathrm{Ar}(\mathcal{O}_G) \times_G \mathcal{P}^{\otimes})$ is right adjoint to π^*.

(2) *P is a Segal morphism.*

(3) *F is a Segal morphism.*

Proof. For (1), the functor π^* simply sends $\mathcal{Q}^{\otimes} \mapsto \mathcal{Q}^{\otimes} \times_G \mathrm{Ar}(\mathcal{O}_G) \times_G \mathcal{P}^{\otimes}$ with structure map given by the product $\pi \times \mathrm{id}$; hence this reduces to checking that (external) products of fibrous patterns are fibrous, which ref??? .

For the rest,ughhhh □

The resulting operad is pronounced "the operad of G-equivariant $\mathcal{O}$-algebras in $\mathcal{C}$ over $\mathcal{E}$" In [NS22, § 5.3], the following properties were verified.

Proposition 3.10. *Let $F : \mathcal{O}^{\otimes} \times_G \mathcal{P}^{\otimes} \to \mathcal{E}^{\otimes}$ be a bifunctor of G-operads and let $\mathcal{C}^{\otimes} \to \mathcal{E}^{\otimes}$ be a functor of G-operads.*

(1) *If $\mathcal{O}$ has one object, then the underlying G-category of $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{E}}(\mathcal{P}; \mathcal{C})$ is the usual G-category $\underline{\mathbf{Alg}}_{\mathcal{E}}(\mathcal{P}; \mathcal{C})$.*

(2) *If $\mathcal{C}^{\otimes}$ is $\mathcal{E}$-monoidal, then $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{E}}(\mathcal{P}; \mathcal{C})$ $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{O}}(\mathcal{C})$ is $\mathcal{O}$-monoidal, and there is a $\mathcal{O}$-monoidal lift $\underline{\mathbf{Alg}}^{\otimes}_{\mathcal{E}}(\mathcal{P}; \mathcal{C}) \to \mathcal{C}^{\otimes}$ to the forgetful functor.*

We specialize to the case that $\ell^{\otimes} = \mathcal{O}^{\otimes} = \mathrm{Comm}_G^{\otimes}$, in which case we write

$$\underline{\mathbf{Alg}}_{\mathcal{P}}^{\otimes}(\mathcal{C}) := \underline{\mathbf{Alg}}_{\mathrm{Comm}_G}^{\otimes}(\mathcal{P};\mathcal{C}).$$

Then, the above diagram instead reads as

$$\mathrm{Comm}_G^{\otimes} \xleftarrow{\pi} \mathrm{Comm}_G^{\otimes} \times_G \mathrm{Ar}(\mathcal{O}_G^{\mathrm{op}}) \times_G \mathcal{P}^{\otimes} \xrightarrow{P\times \mathrm{id}} \mathrm{Comm}_G^{\otimes} \times_G \mathcal{P}^{\otimes} \xrightarrow{F} \mathrm{Comm}_G^{\otimes}.$$

So that the left adjoint is computed by the fibrous localization of the map $\mathcal{Q} \times_G \mathcal{P} \to \mathrm{Comm}_G^{\otimes}$ in the following:

$$\begin{tikzcd}
\pi^*(P\times \mathrm{id})_!\mathcal{Q} \arrow[d] & \simeq & \mathcal{Q} \times_G \mathcal{P} \arrow[dll, "\pi_{\mathcal{Q}}\times \mathrm{id}"] \\
\mathrm{Comm}_G^{\otimes} \times_G \mathcal{P} \arrow[d, "\mathrm{id}\times \pi_{\mathcal{P}}"] \arrow[drr, "F"] & & \\
\mathrm{Comm}_G^{\otimes} \times \mathrm{Comm}_G^{\otimes} \arrow[rr] & & \mathrm{Comm}_G^{\otimes}
\end{tikzcd}$$

in fact, by definition, this is precisely $\mathcal{Q} \otimes \mathcal{P}$. This concludes the proof of theorem 2.22.

3.4. Identifying (co)cartesian I-symmetric monoidal categories.

We begin with the following definition generalizing [HA, Def 2.4.1.1].

Definition 3.11. Let $\mathcal{C}^{\otimes}$ be an I-symmetric monoidal category. A *weak I-Cartesian structure on $\mathcal{C}$* is a G-functor $\pi : \mathcal{C}^{\otimes} \to \mathcal{D}$ such that

(1) for all $f : S \to T$ in I and $C \in \mathcal{C}_S$, the maps $\pi(C) \to \pi(C_s)$ exhibit $\pi(C)$ as the indexed product $\prod_S \pi(C_s)$.
(2) for all π-cocartesian lifts f of active morphisms in I, $\pi(I)$ is an equivalence.

The category of *weak I-cartesian structures from $\mathcal{C}$ to $\mathcal{D}$* is the full G-subcategory

$$\underline{\mathrm{Fun}}_G^{w\times}(\mathcal{C}^{\otimes}, \mathcal{D}) \subset \underline{\mathrm{Fun}}_G(\mathcal{C}^{\otimes}, \mathcal{D})$$

spanned by the weak I-cartesian structures.

Proposition 3.12 (C.f. [HA, Cor 2.4.1.8])**.** *Let $\mathcal{C}^{\otimes}$ be a Cartesian G-symmetric monoidal category whose underlying G-category strongly admits finite I-products and let $\mathcal{D}$ be a G-category which strongly admits finite I-products. Then,*

(1) Let $\pi : \mathcal{D}^{\times} \to \mathcal{D}$ be the canonical I-Cartesian structure on $\mathcal{D}$. Then, $\pi_!$ induces an equivalence of G-categories

$$\pi_! : \underline{\mathrm{Fun}}_I^{\otimes}(\mathcal{C}^{\otimes}, \mathcal{D}^{\times}) \to \underline{\mathrm{Fun}}_I^{w\times}(\mathcal{C}^{\otimes}, \mathcal{D}),$$

(2) The restriction functor

$$\theta : \underline{\mathrm{Fun}}_I^{\otimes}(\mathcal{C}^{\otimes}, \mathcal{D}^{\times}) \to \mathrm{Fun}(\mathcal{C}, \mathcal{D})$$

is fully faithful with image spanned by the I-product preserving functors.
(3) There exists an I-symmetric monoidal equivalence $\mathcal{C}^{\otimes} \simeq \mathcal{C}^{\times}$ which restricts to the identity on underlying G-categories.

Proof. □

3.5. Algebras in cocartesian I-symmetric monoidal categories.

In this subsection, we want to prove the following lemma.

Lemma 3.13 (C.f. [HA, Prop 2.4.3.9])**.** *The following are equivalent for $\mathcal{C}^{\otimes} \in \mathrm{CMon}_{\mathcal{I}}(\mathbf{Cat})$.*

(1) For all unital I-operads $\mathcal{O}^{\otimes}$, the forgetful functor $\underline{\mathbf{Alg}}_{\mathcal{O}}(\mathcal{C}) \to \underline{\mathrm{Fun}}_G(\mathcal{O}, \mathcal{C})$ is an equivalence.
(2) The forgetful functor $\mathrm{CAlg}_I(\mathcal{C}) \to \mathcal{C}$ is an equivalence.
(3) For all morphisms $f : S \to T$ in $\mathcal{I}$, the action map $f_{\otimes} : \mathcal{C}_S \to \mathcal{C}_T$ is left adjoint to the pullback $f^* : \mathcal{C}_T \to \mathcal{C}_S$.

We will prove this in analogy to the non-equivariant case; in particular, the implication (3) $\Longrightarrow$ (1) will closely mimic the proof of [HA, Prop 2.4.3.16].

Proof. (1) implies (2) by choosing $\mathcal{O} = \mathcal{N}_{I\infty}$. The forgetful functor $\mathrm{CAlg}_I(\mathcal{C}) \to \mathcal{C}$ is I-symmetric monoidal by construction, so it suffices to prove that $\mathrm{CAlg}_I(\mathcal{C})$ satisfies condition (3). This is precisely [NS22, Thm 5.3.9]. waaaaaa

Let $\mathcal{C}$ be an I-symmetric monoidal category satisfying (3). Then, WLOG we can replace $\mathcal{C}^{\otimes}$ with $\mathcal{C}^{\amalg}$ by proposition 3.12. Let $\Gamma^* \to \mathbb{F}_*$ be the functor of [HA, Const 2.4.3.1] and let $\underline{\Gamma}^*_G := \mathrm{CoFr}^G \Gamma^*$. Then, define the category

$$\mathcal{D} := \mathcal{O}^{\otimes} \times_{\underline{\mathbb{F}}_{G,*}} \underline{\Gamma}^*_G$$

Define Gamma ◻

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