THE MIXED FUNCTORS OF THE CATEGORY $F_{quad}$: A FIRST STUDY

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Abstract. In previous work, we defined the category of functors $F_{quad}$, associated to $F_2$-vector spaces equipped with a nondegenerate quadratic form. In this paper, we define a special family of objects in the category $F_{quad}$, named the mixed functors. We give the complete decompositions of two elements of this family that give rise to two new infinite families of simple objects in the category $F_{quad}$.

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In 1993, Henn, Lannes and Schwartz established in [5] a very strong relation between the Steenrod algebra and the category $F(p)$ of functors from the category $E^f$ of finite dimensional $F_p$-vector spaces to the category $E$ of all $F_p$-vector spaces, where $F_p$ is the prime field with $p$ elements. To be more precise, they study the category $U$ of unstable modules over the Steenrod algebra localized away from the nilpotent unstable modules $\mathcal{N}il$; they exhibit an equivalence between the quotient category $U/\mathcal{N}il$ and a full subcategory of the category of functors $F(p)$. This equivalence is very useful and allows several important topological results to be derived from algebraic results in the category $F(p)$. For a recent interesting application of this equivalence to the cohomology of Eilenberg MacLane spaces, we refer the reader to the results obtained by Powell in [9].

An important algebraic motivation for the particular interest in the category $F(p)$ follows from the link with the modular representation theory and the cohomology of finite general linear groups. Namely, the evaluation of a functor $F$, object in $F(p)$, on a finite dimensional vector space $V$ is a $F_p[GL(V)]$-module. A fundamental result obtained by Suslin in the appendix of [4] and, independently, by Betley in [2] relates the calculation of extension groups in the category $F(p)$ with certain stable cohomology groups of general linear groups.

It is natural to seek to construct other categories of functors that play a similar rôle for other families of algebraic groups and, in particular, for the orthogonal groups.

In [13], we constructed the functor category $F_{quad}$, which has some good properties as a candidate for the orthogonal group over the field with two elements. For instance, the evaluation functors give rise to a coefficient system that allows us to define a system of homology groups. We obtained, in [13], two families of simple objects in $F_{quad}$ related, respectively, to general linear groups and to orthogonal groups. The purpose of this paper is to define a new family of objects in the category $F_{quad}$, named the mixed functors, which give rise to new simple objects of
the mixed functors are subfunctors of a tensor product between a functor coming from the category \( F := F(2) \) and a functor coming from the subcategory \( F_{\text{iso}} \) of \( F_{\text{quad}} \) defined in [13]. The structure of the mixed functors is very complex, hence it is difficult to give explicit decompositions in general. However, we give the complete decompositions of two significant elements of this family: the functors \( \text{Mix}_{0,1} \) and \( \text{Mix}_{1,1} \). These two mixed functors play a central rôle in the forthcoming paper [12] concerning the decompositions of the standard projective objects \( P_{H_0} \) and \( P_{H_1} \) of \( F_{\text{quad}} \). We prove in [12] that these mixed functors are direct summands of \( P_{H_0} \) and \( P_{H_1} \). The decomposition of \( \text{Mix}_{0,1} \) and \( \text{Mix}_{1,1} \) represents a further step in our project to classify the simple objects of this category.

Recall that in [13] we constructed two families of simple objects in \( F_{\text{quad}} \). The first one is obtained using the fully faithful, exact functor \( \iota : F \to F_{\text{quad}} \), which preserves simple objects. By [7], the simple objects in \( F \) are in one-to-one correspondence with the irreducible representations of general linear groups. The second family is obtained using the fully-faithful, exact functor \( \kappa : F_{\text{iso}} \to F_{\text{quad}} \) which preserves simple objects, where \( F_{\text{iso}} \) is equivalent to the product of the categories of modules over the orthogonal groups. The results of this paper are summarized in the following theorem.

**Theorem.** Let \( \alpha \) be an element in \( \{0, 1\} \).

1. The functor \( \text{Mix}_{\alpha, 1} \) is infinite.
2. There exists a subfunctor \( \Sigma_{\alpha, 1} \) of \( \text{Mix}_{\alpha, 1} \) such that we have the following short exact sequence
   \[
   0 \to \Sigma_{\alpha, 1} \to \text{Mix}_{\alpha, 1} \to \Sigma_{\alpha, 1} \to 0.
   \]
3. The functor \( \Sigma_{\alpha, 1} \) is uniserial with unique composition series given by the decreasing filtration given by the subfunctors \( k_d \Sigma_{\alpha, 1} \) of \( \Sigma_{\alpha, 1} \):
   \[
   \ldots \subset k_d \Sigma_{\alpha, 1} \subset \ldots \subset k_1 \Sigma_{\alpha, 1} \subset k_0 \Sigma_{\alpha, 1} = \Sigma_{\alpha, 1}.
   \]

   a. The head of \( \Sigma_{\alpha, 1} \) (i.e. \( \Sigma_{\alpha, 1}/k_1 \Sigma_{\alpha, 1} \)) is isomorphic to the functor \( \kappa(\text{iso}_{(x, \alpha)}) \) where \( \text{iso}_{(x, \alpha)} \) is a simple object in \( F_{\text{iso}} \).

   b. For \( d > 0 \)
   \[
   k_d \Sigma_{\alpha, 1}/k_{d+1} \Sigma_{\alpha, 1} \simeq L_{\alpha}^{d+1}
   \]
   where \( L_{\alpha}^{d+1} \) is a simple object of the category \( F_{\text{quad}} \) that is neither in the image of \( \iota \) nor in the image of \( \kappa \).

   The functor \( L_{\alpha}^{d+1} \) is a subfunctor of \( \iota(\Lambda^{d+1}) \otimes \kappa(\text{iso}_{(x, \alpha)}) \), where \( \Lambda^{d+1} \) is the \((d+1)\)st exterior power functor.

This theorem and the forthcoming paper [12] lead us to conjecture that there are only three types of simple objects in the category \( F_{\text{quad}} \): those in the image of the functor \( \iota \), those in the image of the functor \( \kappa \) and those which are subfunctors of a tensor product of the form: \( \iota(S) \otimes \kappa(T) \) where \( S \) is a simple object in \( F \) and \( T \) is a simple object in \( F_{\text{iso}} \).

This paper is divided into seven sections. Section 1 recalls the definition of the category \( F_{\text{quad}} \) and the results obtained in [13]. Section 2 gives a general definition of the mixed functors \( \text{Mix}_{V, D, \eta} \) as subfunctors of the tensor product \( \iota(P^2_\xi) \otimes \kappa(\text{iso}_D) \) in \( F_{\text{quad}} \), where \( V \) is an object in \( \mathcal{E}^F \), \( D \) is a quadratic vector space, \( \eta \) is an element in the dual of \( V \otimes D \), \( P^2_\xi \) is the standard projective object of \( F \) obtained by the Yoneda lemma and \( \text{iso}_D \) is an isotropic functor in \( F_{\text{iso}} \). Section 3 studies the mixed functors \( \text{Mix}_{V, D, \eta} \) such that \( \text{dim}(D) = 1 \) and \( \text{dim}(V) = 1 \). We define, in
1. The category $\mathcal{F}_{\text{quad}}$

We recall in this section some definitions and results about the category $\mathcal{F}_{\text{quad}}$ obtained in [13].

Let $\mathcal{E}_q$ be the category having as objects finite dimensional $\mathbb{F}_2$-vector spaces equipped with a non degenerate quadratic form and with morphisms linear maps that preserve the quadratic forms. By the classification of quadratic forms over the field $\mathbb{F}_2$ (see, for instance, [8]) we know that only spaces of even dimension can be nondegenerate and, for a fixed even dimension, there are two non-equivalent nondegenerate spaces, which are distinguished by the Arf invariant. We will denote by $H_0$ (resp. $H_1$) the nondegenerate quadratic space of dimension two such that $\text{Arf}(H_0) = 0$ (resp. $\text{Arf}(H_1) = 1$). The orthogonal sum of two nondegenerate quadratic spaces $(V, q_V)$ and $(W, q_W)$ is, by definition, the quadratic space $(V \oplus W, q_{V\oplus W})$ where $q_{V\oplus W}(v, w) = q_V(v) + q_W(w)$. Recall that the spaces $H_0 \perp H_0$ and $H_1 \perp H_1$ are isomorphic. Observe that the morphisms of $\mathcal{E}_q$ are injective linear maps and this category does not admit push-outs or pullbacks. There exists a pseudo push-out in $\mathcal{E}_q$ that allows us to generalize the construction of the category of co-spans of Bénabou [1] and thus to define the category $\mathcal{T}_q$ in which there exist retractions.

**Definition 1.1.** The category $\mathcal{T}_q$ is the category having as objects those of $\mathcal{E}_q$ and, for $V$ and $W$ objects in $\mathcal{T}_q$, $\text{Hom}_{\mathcal{T}_q}(V, W)$ is the set of equivalence classes of diagrams in $\mathcal{E}_q$ of the form $V \xrightarrow{f} X \xleftarrow{g} W$ for the equivalence relation generated by the relation $\mathcal{R}$ defined as follows: $V \xrightarrow{f} X_1 \xleftarrow{g} W \quad \mathcal{R} \quad V \xrightarrow{u} X_2 \xleftarrow{v} W$ if there exists a morphism $\alpha$ of $\mathcal{E}_q$ such that $\alpha \circ f = u$ and $\alpha \circ g = v$. The composition is defined using the pseudo push-out. The morphism of $\text{Hom}_{\mathcal{T}_q}(V, W)$ represented by the diagram $V \xrightarrow{f} X \xleftarrow{g} W$ will be denoted by $[V \xrightarrow{f} X \xleftarrow{g} W]$.

By definition, the category $\mathcal{F}_{\text{quad}}$ is the category of functors from $\mathcal{T}_q$ to $\mathcal{E}$. Hence $\mathcal{F}_{\text{quad}}$ is abelian and has enough projective objects. By the Yoneda lemma, for any object $V$ of $\mathcal{T}_q$, the functor $P_V = F_2[\text{Hom}_{\mathcal{T}_q}(V, -)]$ is a projective object and there is a natural isomorphism: $\text{Hom}_{\mathcal{F}_{\text{quad}}}(P_V, F) \simeq F(V)$, for all objects $F$ of $\mathcal{F}_{\text{quad}}$. The set of functors $\{P_V | V \in S\}$, named the standard projective objects in $\mathcal{F}_{\text{quad}}$. 

particular, the subfunctor $\Sigma_{\alpha, 1}$ of the mixed functor $\text{Mix}_{\alpha, 1}$ given in the second point of the previous theorem. In section 4, we deduce a filtration of the functor $\iota(P_{\Sigma_{\alpha, 1}} \otimes \kappa(\text{iso}_{(x, \alpha)})$ from the polynomial filtration in the category $\mathcal{F}$. Section 5 gives a filtration of the functors $\Sigma_{\alpha, 1}$, defined in section 3, and we obtain the existence of a natural map from the subquotients of this filtration to the functors $\iota(\Lambda^\alpha) \otimes \kappa(\text{iso}_{(x, \alpha)})$, by relating this filtration to that introduced in the previous section. Section 6 gives the structure of the functors $\Sigma_{\alpha, 1}$ and prove their simplicity. Section 7 proves the structure of the functors $\text{Mix}_{\alpha, 1}$ given in the previous theorem.

The results contained in this paper extend results obtained in the author’s PhD thesis [11]. The author wishes to thank her PhD supervisor, Lionel Schwartz, for his guidance, as well as Geoffrey Powell and Aurélien Djament for numerous useful discussions and thank Serge Bouc for suggesting that the methods used in the author’s thesis should be sufficient to establish the uniseriality of the functors $\Sigma_{\alpha, 1}$. 


is a set of projective generators of $\mathcal{F}_{\text{quad}}$, where $\mathcal{S}$ is a set of representatives of isometry classes of nondegenerate quadratic spaces.

There is a forgetful functor $\epsilon : \mathcal{T}_q \to \mathcal{E}'$ in $\mathcal{F}_{\text{quad}}$, defined by $\epsilon(V) = O(V)$ and

$$\epsilon([V \xrightarrow{f} W \perp W', \perp W]) = p_g \circ O(f)$$

where $p_g$ is the orthogonal projection from $W \perp W'$ to $W$ and $O : \mathcal{E}_q \to \mathcal{E}'$ is the functor which forgets the quadratic form. By the fullness of the functor $\epsilon$ and an argument of essential surjectivity, we obtain the following theorem.

**Theorem 1.2.** [13] There is a functor $\iota : \mathcal{F} \to \mathcal{F}_{\text{quad}}$, which is exact, fully faithful and preserves simple objects.

In order to define another subcategory of $\mathcal{F}_{\text{quad}}$, we consider the category $\mathcal{E}_{\text{deg}}$ having as objects finite dimensional $\mathbb{F}_2$-vector spaces equipped with a (possibly degenerate) quadratic form and with morphisms injective linear maps that preserve the quadratic forms. A useful relation between the categories $\mathcal{E}_q$ and $\mathcal{E}_{\text{deg}}$ is given by the following theorem, which can be regarded as Witt’s theorem for degenerate quadratic forms.

**Theorem 1.3.** Let $V$ be a nondegenerate quadratic space, $D$ and $D'$ subquadratic spaces (possibly degenerate) of $V$ and $f : D \to D'$ an isometry. Then, there exists an isometry $f : V \to V$ such that the following diagram is commutative:

$$
\begin{array}{ccc}
V & \xrightarrow{f} & V \\
\downarrow & & \downarrow \\
D & \xrightarrow{f} & D'.
\end{array}
$$

**Proof.** For a proof of this result, we refer the reader to [3] §4, Theorem 1. □

The category $\mathcal{E}_{\text{deg}}$ admits pullbacks; consequently the category of spans $\text{Sp}(\mathcal{E}_{\text{deg}})$ ([11]) is defined. By definition, the category $\mathcal{F}_{\text{iso}}$ is the category of functors from $\text{Sp}(\mathcal{E}_{\text{deg}})$ to $\mathcal{E}$. As in the case of the category $\mathcal{F}_{\text{quad}}$, the category $\mathcal{F}_{\text{iso}}$ is abelian and has enough projective objects; by the Yoneda lemma, for any object $V$ of $\text{Sp}(\mathcal{E}_{\text{deg}})$, the functor $Q_V = \mathbb{F}_2[\text{Hom}_{\text{Sp}(\mathcal{E}_{\text{deg}})}(V, -)]$ is a projective object in $\mathcal{F}_{\text{iso}}$. The category $\mathcal{F}_{\text{iso}}$ is related to $\mathcal{F}_{\text{quad}}$ by the following theorem.

**Theorem 1.4.** [13] There is a functor $\kappa : \mathcal{F}_{\text{iso}} \to \mathcal{F}_{\text{quad}}$, which is exact, fully-faithful and preserves simple objects.

We obtain the classification of the simple objects of the category $\mathcal{F}_{\text{iso}}$ from the following theorem.

**Theorem 1.5.** [13] There is a natural equivalence of categories

$$\mathcal{F}_{\text{iso}} \simeq \prod_{V \in \mathcal{S}} \mathbb{F}_2[O(V)] - \text{mod}$$

where $\mathcal{S}$ is a set of representatives of isometry classes of quadratic spaces (possibly degenerate) and $O(V)$ is the orthogonal group.

The object of $\mathcal{F}_{\text{iso}}$ that corresponds, by this equivalence, to the module $\mathbb{F}_2[O(V)]$ is the isotropic functor $\text{iso}_V$, defined in [13]. The family of isotropic functors forms a set of projective generators and injective cogenerators of $\mathcal{F}_{\text{iso}}$. Recall that the
isotropic functor \( \text{iso}_V : \text{Sp}(\mathcal{E}^{\text{deg}}_q) \rightarrow \mathcal{E} \) of \( \mathcal{F}_{\text{iso}} \) is the image of \( Q_V \) by the morphism \( \alpha_V : Q_V \rightarrow DQ_V \) which corresponds by the Yoneda lemma to the element \((\text{Id}_V)^* \) of \( DQ_V(V) \), where \((\text{Id}_V)^* \) is defined by:

\[
(\text{Id}_V)^*([f]) = 1 \quad \text{and} \quad (\text{Id}_V)^*([f]) = 0 \quad \text{for} \quad f \neq \text{Id}_V
\]

where we denote by \([f]\) a canonical generator of \( DQ_V(V) \). This definition and that of the functor \( \kappa : \mathcal{F}_{\text{iso}} \rightarrow \mathcal{F}_{\text{quad}} \), will be denoted by \( \kappa \).

**Proposition 1.6.** The following equivalent definition of the functor \( \kappa(\text{iso}_V) \) holds.

- For a morphism \( m = [W \xrightarrow{f} Y \xleftarrow{g} X] \) in \( T_q \) and a canonical generator \([h]\) of \( \kappa(\text{iso}_V)(W) \), we consider the following diagram in \( \mathcal{E}^{\text{deg}}_q \):

\[
\begin{array}{ccc}
X & \xrightarrow{g} & Y \\
\downarrow{h} & & \\
V & \xrightarrow{f} & W
\end{array}
\]

If the pullback of this diagram in \( \mathcal{E}^{\text{deg}}_q \) is \( V \), this gives rise to a unique morphism \( h' : V \rightarrow X \) in \( \mathcal{E}^{\text{deg}}_q \), such that \( f \circ h = g \circ h' \). In this case, \( \kappa(\text{iso}_V)(m)[h] = [h'] \). Otherwise, \( \kappa(\text{iso}_V)(m)[h] = 0 \).

**Notation 1.7.** In this paper, a canonical generator of \( \kappa(\text{iso}_D)(W) \) will be denoted by: \([D \xrightarrow{h} W]\) or, more simply, by \([h]\).

We end this section by a useful corollary of Theorem\[1.4\] and \[1.5\]. For \( \alpha \in \{0, 1\} \), let \((x, \alpha)\) be the degenerate quadratic space of dimension one generated by \( x \) such that \( q(x) = \alpha \).

**Corollary 1.8.** The functors \( \kappa(\text{iso}_{(x, 0)}) \) and \( \kappa(\text{iso}_{(x, 1)}) \) are simple in \( \mathcal{F}_{\text{quad}} \).

**Proof.** It is a straightforward consequence of the triviality of the orthogonal groups \( O(x, 0) \) and \( O(x, 1) \).

### 2. Definition of the mixed functors

The aim of this section is to define the mixed functors: for this, we consider the functors \( \iota(P^F_V) \otimes \kappa(\text{iso}_D) \) in \( \mathcal{F}_{\text{quad}} \) where \( V \) is an object in \( \mathcal{E}^f \), \( P^F_V \) is the standard projective object of \( \mathcal{F} \) obtained by the Yoneda lemma, \( D \) is an object in \( \mathcal{E}^{\text{deg}}_q \), and \( \iota : \mathcal{F} \rightarrow \mathcal{F}_{\text{quad}} \) and \( \kappa : \mathcal{F}_{\text{iso}} \rightarrow \mathcal{F}_{\text{quad}} \) are the functors defined in Theorem\[1.2\] and \[1.3\] respectively. A canonical generator of \( P^F_V(W) \simeq \mathbb{F}_2[\text{Hom}_{\mathcal{E}}(V, W)] \) will be denoted by \([f]\).

**Notation 2.1.** In this paper, the bilinear form associated to a quadratic space \( V \) will be denoted by \( B_V \).

**Proposition 2.2.** Let \( D \) be an object in \( \mathcal{E}^{\text{deg}}_q \), \( V \) be an object in \( \mathcal{E}^f \), \( \eta \) be an element in the dual of \( V \otimes D \) and \( W \) be an object in \( T_q \), the subvector space of \((\iota(P^F_V) \otimes \kappa(\text{iso}_D))(W) \) generated by the elements:

\[
[f] \otimes [D \xrightarrow{h} W]
\]
such that

\[ \forall v \in V, \forall d \in D \quad B_W(f(v), h(d)) = \eta(v \otimes d) \]

defines a subfunctor of \( \iota(P_V^\mathcal{F}) \otimes \kappa(\text{iso}_D) \) which will be denoted by \( \text{Mix}_{V,D,\eta} \) and called the mixed functor associated to \( V, D \) and \( \eta \).

Proof. It is sufficient to verify that, for each morphism \( M = [W \xrightarrow{k} Y \xleftarrow{l} Z] \) of \( T_q \) and each generator \([f] \otimes [D \xrightarrow{h} W]\) of \( \text{Mix}_{V,D,\eta}(W) \),

\[ \text{Mix}_{V,D,\eta}(M)([f] \otimes [D \xrightarrow{h} W]) \in \text{Mix}_{V,D,\eta}(Z). \]

Consider the following diagram in \( E^\text{deg}_q \):

\[
\begin{array}{ccc}
Z & \xrightarrow{l} & Y \\
\downarrow & & \downarrow \\
D & \xrightarrow{h} & W & \xrightarrow{k} & Y.
\end{array}
\]

- If the pullback of this diagram in \( E^\text{deg}_q \) is \( D \), namely if \( k \circ h(D) \subset l(Z) \), this gives rise to a unique morphism \( h' \) from \( D \) to \( Z \) in \( E^\text{deg}_q \), such that \( k \circ h = l \circ h' \) that is, the following diagram commutes

\[
\begin{array}{ccc}
D & \xrightarrow{h'} & Z \\
\downarrow & & \downarrow \\
D & \xrightarrow{h} & W & \xrightarrow{k} & Y.
\end{array}
\]

In this case, by Proposition 1.6 we have:

\[ \text{Mix}_{V,D,\eta}(M)([f] \otimes [D \xrightarrow{h} W]) = ([p_l \circ k \circ f] \otimes [D \xrightarrow{h'} Z]) \]

where \( p_l \) is the orthogonal projection associated to \( l \). For an element \( v \) in \( V \) and \( d \) in \( D \), we have:

\[ B_V(f(v), h(d)) = B_V(k \circ f(v), h(d)). \]

Since the pullback of the diagram considered previously is \( D \), we have: \( k \circ h(D) \subset l(Z) \). Consequently:

\[ B_V(f(v), h(d)) = B_Z(p_l \circ k \circ f(v), h(d)) = B_Z(h'(d)). \]

Thus, if \( B_V(f(-), h(-)) = \eta \) then \( B_Z(p_l \circ k \circ f(-), h'(-)) = \eta \), therefore \( ([p_l \circ k \circ f] \otimes [D \xrightarrow{h'} Z]) \) is an element of \( \text{Mix}_{V,D,\eta}(Z) \).

- Otherwise we have, by Proposition 1.6

\[ \text{Mix}_{V,D,\eta}(M)([f] \otimes [D \xrightarrow{h} W]) = 0. \]

\[ \square \]

**Remark 2.3.** The terminology "mixed functors" is chosen to reflect the fact that these functors are subfunctors of a tensor product of a functor coming from the category \( \mathcal{F} \) and a functor coming from the category \( \mathcal{F}_{\text{iso}} \).

We obtain the following decomposition of the functors \( \iota(P_V^\mathcal{F}) \otimes \kappa(\text{iso}_D) \).
Lemma 2.4. For $D$ an object in $\mathcal{E}_{q}^{\text{deg}}$ and $V$ an object in $\mathcal{E}$ we have:
\[
\iota(P_{V}^{F}) \otimes \kappa(\text{iso}_{D}) = \bigoplus_{\eta \in (V \otimes D)^{*}} \text{Mix}_{V,D,\eta}.
\]

Proof. For two different elements $\eta$ and $\eta'$ in $(V \otimes D)^{*}$, we have:
\[
\text{Mix}_{V,D,\eta}(W) \cap \text{Mix}_{V,D,\eta'}(W) = \{0\}
\]
for $W$ an object in $\mathcal{T}_{q}$. Thus, we have the decompositions: $(\iota(P_{V}^{F}) \otimes \kappa(\text{iso}_{D}))(W) = \bigoplus_{\eta \in (V \otimes D)^{*}} \text{Mix}_{V,D,\eta}(W)$, for all objects $W$ in $\mathcal{T}_{q}$. Since $\text{Mix}_{V,D,\eta}$ is a subfunctor of $\iota(P_{V}^{F}) \otimes \kappa(\text{iso}_{D})$ by Proposition 2.2, we deduce the result. \(\square\)

Remark 2.5. In the definition of the mixed functors, we don’t impose that $h(D) \cap f(V) = \{0\}$. Nevertheless, we can define similar functors with this condition, which give rise to quotient functors to the mixed functors defined in Proposition 2.2. These functors will be useful for a later general study of the mixed functors.

3. The Functors $\text{Mix}_{V,D,\eta}$ Such that $\dim(D) = 1$ and $\dim(V) = 1$

The aim of this section is to give some general results about the four simplest mixed functors of $\mathcal{F}_{\text{quad}}$ obtained in the case of $\dim(D) = \dim(V) = 1$. The motivation of the particular interest in this case is the study of the projective generators $P_{H_{0}}$ and $P_{H_{1}}$ of $\mathcal{F}_{\text{quad}}$. In fact, we prove in [12], that the mixed functors that are direct summands of these two standard projective generators of $\mathcal{F}_{\text{quad}}$ verify the conditions $\dim(D) = \dim(V) = 1$.

When $V$ and $D$ are spaces of dimension one, we will denote by $\text{Mix}_{\alpha,\beta}$, where $\alpha$ and $\beta$ are elements of $\{0, 1\}$, the functor $\text{Mix}_{V,D,\eta}$ such that $V \simeq F_{2}$, $D \simeq (x, \alpha)$ and $\eta = \beta$. We have the following result.

Lemma 3.1. Let $W$ be an object in $\mathcal{T}_{q}$, if $[f] \otimes [(x, \alpha) \overset{h}{\rightarrow} W]$ is a canonical generator of $\text{Mix}_{\alpha,\beta}(W)$, then $[f + h(x)] \otimes [(x, \alpha) \overset{h}{\rightarrow} W]$ is a canonical generator of $\text{Mix}_{\alpha,\beta}(W)$.

Proof. This is a straightforward consequence of the fact that the bilinear form associated to a quadratic form is alternating. \(\square\)

In order to make this symmetry clearer in the set of canonical generators of $\text{Mix}_{\alpha,\beta}(W)$ and to introduce an action of the symmetric group $\mathfrak{S}_{2}$ on this set, we use a slightly different description of the canonical generators of $\text{Mix}_{\alpha,\beta}(W)$ corresponding to a reindexing of these canonical generators.

Definition 3.2. For $\alpha$ and $\beta$ elements of $\{0, 1\}$, we consider the following set:
\[
N_{\alpha,\beta}^{W} = \{(w_{1}, w_{2}) \mid w_{1} \in W, w_{2} \in W, q(w_{1} + w_{2}) = \alpha, B(w_{1}, w_{2}) = \beta\}.
\]

We have the following result.

Lemma 3.3. For $D \simeq (x, \alpha)$ and $\eta = \beta$, we have:
\[
\text{Mix}_{\alpha,\beta}(W) \simeq F_{2}[N_{\alpha,\beta}^{W}]
\]
where $W$ is an object in $\mathcal{T}_{q}$.
Proof. The generator of the vector space $V$ of dimension one will be denoted by $a$. There is an isomorphism:

$$f_W : \text{Mix}_{\alpha, \beta}(W) \rightarrow \mathbb{F}_2[N^W_{\alpha, \beta}]$$

$$[f] \otimes [(x, \alpha) \xrightarrow{h} W] \mapsto [(f(a) + h(x), f(a)],$$

of which the inverse is given by:

$$f_{W}^{-1} : \mathbb{F}_2[N^W_{\alpha, \beta}] \rightarrow \text{Mix}_{\alpha, \beta}(W)$$

$$[(w_1, w_2)] \mapsto [k] \otimes [(x, \alpha) \xrightarrow{l} W]$$

where $k : V \rightarrow W$ is defined by $k(a) = w_2$ and $l : (x, \alpha) \rightarrow W$ is defined by $l(x) = w_1 + w_2$. □

Notation 3.4. Henceforth, we will use the basis given by the set $N^W_{\alpha, \beta}$ to represent the elements of $\text{Mix}_{\alpha, \beta}(W)$.

Thus, the canonical generator $[f] \otimes [(x, \alpha) \xrightarrow{h} W]$ of $\text{Mix}_{\alpha, \beta}(W)$ is represented by $[(f(a) + h(x), f(a))]$ and $[f + h(x)] \otimes [(x, \alpha) \xrightarrow{l} W]$, which is also a canonical generator of $\text{Mix}_{\alpha, \beta}(W)$ by Lemma 3.1 is represented by $[(f(a), f(a) + h(x))]$.

We have the following lemma.

Lemma 3.5. The symmetric group $\mathfrak{S}_2$ acts on the functor $\text{Mix}_{\alpha, \beta}$.

Proof. Let $W$ be an object of $\mathcal{T}_q$, we define an action of $\mathfrak{S}_2 = \{\text{Id}, \tau\}$ on $\text{Mix}_{\alpha, \beta}(W)$ by:

$$\tau. [(w_1, w_2)] = [(w_2, w_1)].$$

We leave the reader to verify that the linear maps $\tau_W$

$$\tau_W : \text{Mix}_{\alpha, \beta}(W) \rightarrow \text{Mix}_{\alpha, \beta}(W)$$

$$[(w_1, w_2)] \mapsto [(w_2, w_1)]$$

define a natural transformation. □

This lemma allows us to define an object in $\mathcal{F}_{\text{quad}}$ by considering the invariants by this action.

Definition 3.6. Let $\Sigma_{\alpha, \beta}$ be the subfunctor of $\text{Mix}_{\alpha, \beta}$ defined by considering the invariants of $\text{Mix}_{\alpha, \beta}(W)$ by the action of the symmetric group $\mathfrak{S}_2$.

In the following, we will focus on study the functors $\text{Mix}_{0,1}$ and $\text{Mix}_{1,1}$. These two functors are particularly interesting since they are direct summands of $P_{H_0}$ and $P_{H_1}$ (see [12]).

We have the following lemma.

Lemma 3.7. Let $W$ be an object in $\mathcal{T}_q$ and $[(w_1, w_2)]$ be a generator of $\text{Mix}_{0,1}(W)$, then the vectors $w_1$ and $w_2$ are linearly independent.

Proof. This is a straightforward consequence of the fact that the bilinear form $B$ is alternating. □

We deduce the following lemma.

Lemma 3.8. Let $W$ be an object in $\mathcal{T}_q$, the action of $\mathfrak{S}_2$ on the set of canonical generators of $\text{Mix}_{0,1}(W)$ is free.
Lemma 3.8 has no analogue for the functors Mix\(_{a,1}\) and Mix\(_{1,0}\) since, in these two cases, the action of \(\mathfrak{S}_2\) is not free.

Remark 3.9. We deduce from Lemma 3.7 that the two functors Mix\(_{a,1}\), coincide with the functors mentioned in Remark 2.5.

We give the following general result about the free actions of the group \(\mathfrak{S}_2\).

Lemma 3.10. If \(A\) is a finite set equipped with a free action of the group \(\mathfrak{S}_2\), then, there exists a short exact sequence of \(\mathfrak{S}_2\)-modules:
\[
0 \rightarrow F_2[A]^{\mathfrak{S}_2} \rightarrow F_2[A] \rightarrow F_2[A]^{\mathfrak{S}_2} \rightarrow 0.
\]

Proof. We deduce from the action of \(\mathfrak{S}_2\) on \(A\), the existence of the canonical inclusion of the invariants in \(F_2[A]\): \(F_2[A]^{\mathfrak{S}_2} \rightarrow F_2[A]\). The norm \(F_2[A] \xrightarrow{1+} F_2[A]\) induces a linear map: \(F_2[A] \xrightarrow{g} F[A]^{\mathfrak{S}_2}\), such that the composition
\[
F_2[A]^{\mathfrak{S}_2} \xrightarrow{f} F_2[A] \xrightarrow{g} F_2[A]^{\mathfrak{S}_2}
\]
is trivial. We verify that this defines a short exact sequence. \(\square\)

We deduce the following proposition.

Proposition 3.11. There exists a short exact sequence
\[
0 \rightarrow \Sigma_{a,1} \rightarrow \text{Mix}_{a,1} \rightarrow \Sigma_{a,1} \rightarrow 0.
\]

Proof. This is a straightforward consequence of Lemma 3.8 and Lemma 3.10. \(\square\)

Notation 3.12. We will denote by \([\{w_1, w_2\}\] the image of the element \([\{w_1, w_2\}\] of \(\text{Mix}_{a,1}(W)\) in \(\Sigma_{a,1}(W)\) by the surjection \(\text{Mix}_{a,1}(W) \twoheadrightarrow \Sigma_{a,1}(W)\).

Remark 3.13. Lemma 3.8 has no analogue for the functors Mix\(_{0,0}\) and Mix\(_{1,0}\) since, in these two cases, the action of the group \(\mathfrak{S}_2\) is not free. Nevertheless, we can apply similar arguments to the functors mentioned in Remark 2.5 corresponding to the functors Mix\(_{0,0}\) and Mix\(_{1,0}\).

Remark 3.14. It is shown in [12] that the functors Mix\(_{0,1}\) and Mix\(_{1,1}\) are indecomposable. Consequently, the short exact sequence (3.11.1) is not split for the functors Mix\(_{0,1}\) and Mix\(_{1,1}\).

4. Study of the functor \(\iota(P^F_{\mathbb{F}_2}) \otimes \kappa(\text{iso}(x,\alpha))\)

By Proposition 2.2, the functor Mix\(_{a,1}\) is a subfunctor of \(\iota(P^F_{\mathbb{F}_2}) \otimes \kappa(\text{iso}(x,\alpha))\). Consequently, in order to obtain the decomposition of Mix\(_{a,1}\), we study, in this section, the functor \(\iota(P^F_{\mathbb{F}_2}) \otimes \kappa(\text{iso}(x,\alpha))\).

4.1. Filtration of the functors \(\iota(P^F_{\mathbb{F}_2}) \otimes \kappa(\text{iso}(x,\alpha))\). We define, below, the filtration of the functors \(\iota(P^F_{\mathbb{F}_2}) \otimes \kappa(\text{iso}(x,\alpha))\) induced by the polynomial filtration of the functor \(P^F_{\mathbb{F}_2}\) in the category \(\mathcal{F}\). First we recall the essential results concerning the polynomial functors in the category \(\mathcal{F}\). We refer the interested reader to [5], [10] and [6] for details on the subject.
Notation 4.1. Henceforth, in order to simplify the notation, we will denote the functor \( \iota(P^F_2 \otimes \kappa(\text{iso}_{(x, \alpha)}) \) by \( P^F_2 \otimes \text{iso}_\alpha \) and, if \( F \neq P^F_2 \), we will denote the functor \( \iota(F \otimes \kappa(\text{iso}_{(x, \alpha)}) \) by \( F \otimes \text{iso}_\alpha \).

Definition 4.2. Let \( F \) be an object in \( \mathcal{F} \) and \( d \) an integer, the functor \( q_d F \) is the largest polynomial quotient of degree \( d \) of the functor \( F \).

Notation 4.3. We denote by \( k_d F \) the kernel of \( F \rightarrow q_d F \).

We have the following result.

Proposition 4.4. For an integer \( d \), the functors \( k_d F \) define a decreasing filtration of the functor \( F \).

Thus, for the standard projective functor \( P^F_2 \), we have the following short exact sequence:

\[
0 \rightarrow k_d P^F_2 \rightarrow P^F_2 \xrightarrow{f_d} q_d P^F_2 \rightarrow 0.
\]

Furthermore, the decreasing filtration of \( P^F_2 \) given by the functors \( k_d P^F_2 \) is separated (that is \( \cap k_d P^F_2 = 0 \)).

We recall below the description of the vector space \( k_d P^F_2(V) \) for \( V \) an object in \( \mathcal{E}^f \).

Proposition 4.5. The vector space \( k_d P^F_2(V) \) is generated by the elements

\[
\sum_{z \in \mathcal{L}} [z]
\]

where \( \mathcal{L} \) is a subvector space of \( V \) of dimension \( d + 1 \).

Notation 4.6. The subvector space of \( V \) or subquadratic space of \( (V, q_V) \) generated by \( v_1, \ldots, v_n \) will be denoted by \( \text{Vect}(v_1, \ldots, v_n) \).

The subquotients of the filtration of the functor \( P^F_2 \) are given in the following proposition.

Proposition 4.7. For \( d \) a non-negative integer, there exists a short exact sequence

\[
0 \rightarrow k_{d+1} P^F_2 \rightarrow k_d P^F_2 \xrightarrow{g_d} \Lambda^{d+1} \rightarrow 0
\]

where \( \Lambda^{d+1} \) is the \((d+1)\)-th exterior power and the map \( g_d \) is defined in the following way: for \( V \) an object in \( \mathcal{E}^f \) and \( \mathcal{L} \) the subvector space of \( V \) of dimension \( d + 1 \) generated by the elements \( l_1, \ldots, l_{d+1} \) of \( V \), we have:

\[
(g_d)(\sum_{z \in \mathcal{L}} z) = l_1 \wedge \ldots \wedge l_{d+1}.
\]

By taking tensor product with the isotropic functors \( \text{iso}_\alpha \), Proposition 4.4 and the short exact sequences (4.4.1) and (4.7.1) give rise to the following result.

Corollary 4.8. (1) For \( d \) an integer, the functors \( (k_d P^F_2) \otimes \text{iso}_\alpha \) define a decreasing separated filtration of the functor \( P^F_2 \otimes \text{iso}_\alpha \).

(2) There exist the following short exact sequences in \( \mathcal{F}_{\text{quad}} \):

\[
0 \rightarrow (k_d P^F_2) \otimes \text{iso}_\alpha \rightarrow P^F_2 \otimes \text{iso}_\alpha \xrightarrow{f_d \otimes \text{iso}_\alpha} (q_d P^F_2) \otimes \text{iso}_\alpha \rightarrow 0;
\]

\[
0 \rightarrow (k_{d+1} P^F_2) \otimes \text{iso}_\alpha \rightarrow (k_d P^F_2) \otimes \text{iso}_\alpha \xrightarrow{g_d \otimes \text{iso}_\alpha} (\Lambda^{d+1}) \otimes \text{iso}_\alpha \rightarrow 0.
\]
Remark 4.9. We obtain similar results by taking the tensor product between the short exact sequence \([4.7.1]\) and the isotropic functors \(iso_T\). This will be useful for a general study of the mixed functors.

5. Filtration of the functors \(\Sigma_{\alpha,1}\)

In this section, we define a filtration of the functors \(\Sigma_{\alpha,1}\) that we will relate below to the filtration of \(P_T \otimes iso_\alpha\) obtained in the previous section.

Definition 5.1. For \(V\) an object of \(\mathcal{T}_q\) and \(d\) an integer, let \(k_d\Sigma_{\alpha,1}(V)\) be the subvector space of \(\Sigma_{\alpha,1}(V)\) generated by the elements:

\[
\sum_{z \in \mathcal{L}} [(x + z, y + z)],
\]

where \([(x, y)] \in \Sigma_{\alpha,1}(V)\) and \(\mathcal{L}\) is a subvector space of \(\text{Vect}(x + y)^\perp\) of dimension \(d\).

Proposition 5.2. The spaces \(k_d\Sigma_{\alpha,1}(V)\), for \(V\) an object in \(\mathcal{T}_q\), define a subfunctor of \(\Sigma_{\alpha,1}\).

Proof. For a morphism \(T\) in \(\text{Hom}_{\mathcal{T}_q}(V, W)\), it is straightforward to check, by definition of \(\text{Mix}_{\alpha,1}(T)\), that the image of \(k_d\Sigma_{\alpha,1}(V)\) by

\[
\Sigma_{\alpha,1}(T) : k_d\Sigma_{\alpha,1}(V) \rightarrow \Sigma_{\alpha,1}(W)
\]

is a subvector space of \(k_d\Sigma_{\alpha,1}(W)\). \(\square\)

Proposition 5.3. The functors \(k_d\Sigma_{\alpha,1}\) define a separated decreasing filtration of the functor \(\Sigma_{\alpha,1}\)

\[
\ldots \subset k_d\Sigma_{\alpha,1} \subset \ldots \subset k_1\Sigma_{\alpha,1} \subset k_0\Sigma_{\alpha,1} = \Sigma_{\alpha,1}.
\]

Proof. To show that the filtration is decreasing, it is sufficient to prove, for an object \(V\) of \(\mathcal{T}_q\), that there is an inclusion of vector spaces:

\[
k_{d+1}\Sigma_{\alpha,1}(V) \subset k_d\Sigma_{\alpha,1}(V).
\]

We consider a generator of \(k_{d+1}\Sigma_{\alpha,1}(V)\): \(v = \sum_{z \in \mathcal{L}} [(x + z, y + z)]\) where \([(x, y)] \in \Sigma_{\alpha,1}(V)\) and \(\mathcal{L}\) is the subvector space of \(\text{Vect}(x + y)^\perp\) of dimension \(d+1\) generated by the elements \(l_1, \ldots, l_{d+1}\), and we consider the following decomposition into direct summands: \(\mathcal{L} = \text{Vect}(l_1, \ldots, l_d) \oplus \text{Vect}(l_{d+1}) = \mathcal{L}' \oplus \text{Vect}(l_{d+1})\). By considering separately the elements \(z\) in \(\mathcal{L}\) with an nonzero component on \(l_{d+1}\) and those with a zero component on \(l_{d+1}\), we obtain:

\[
v = \sum_{z \in \mathcal{L}'} [(x + z, y + z)] + \sum_{z \in \mathcal{L}'} [(x + l_{d+1}, y + l_{d+1}, z)].
\]

By definition of \(k_d\Sigma_{\alpha,1}\) we have: \(\sum_{z \in \mathcal{L}'} [(x + z, y + z)] \in k_d\Sigma_{\alpha,1}(V)\) and \(\sum_{z \in \mathcal{L}'} [(x + l_{d+1}, y + l_{d+1}, z)] \in k_d\Sigma_{\alpha,1}(V)\) since \([(x + l_{d+1}, y + l_{d+1})] \in \Sigma_{\alpha,1}(V)\). Consequently \(v \in \Sigma_{\alpha,1}(V)\).

One verifies easily that the filtration is separated. \(\square\)

In the following result, we relate the filtration of the functors \(\Sigma_{\alpha,1}\) and the filtration of \(P_T \otimes iso_\alpha\) obtained from the polynomial filtration in Corollary 4.8.
Lemma 5.4. The composition

\[ k_d \Sigma_{\alpha,1} \rightarrow \Sigma_{\alpha,1} \rightarrow \text{Mix}_{\alpha,1} \rightarrow P_\beta \otimes \text{iso}_\alpha \rightarrow f_d \otimes \text{iso}_\alpha \rightarrow q_d P_\beta \otimes \text{iso}_\alpha \]

is zero.

Proof. Let \( V \) be an object in \( \mathcal{T}_q \) and \( v \) a generator of \( k_d \Sigma_{\alpha,1}(V) \): \( v = \sum_{z \in \mathcal{L}} \{ [y + z, y' + z] \} \) where \( [y, y'] \in \Sigma_{\alpha,1}(V) \) and \( L \) is the subvector space of \( \text{Vect}(y + y')^\perp \) of dimension \( d \) generated by the elements \( l_1, \ldots, l_d \).

Let \( h \) be the element of \( \text{Hom}_{\mathcal{E}_d}((x, \alpha), V) \) such that \( h(x) = y + y' \), we have:

\[
\sum_{z \in \mathcal{L}} ([y + z] + [y' + z]) \otimes [h] = \sum_{z \in \mathcal{L}} ([y + z] + [y' + z] + [z]) \otimes [h] = \sum_{z' \in \mathcal{L} \oplus \text{Vect}(y)} [z'] \otimes [h] + \sum_{z'' \in \mathcal{L} \oplus \text{Vect}(y')} [z''] \otimes [h].
\]

By Proposition 4.3, we have:

\[
\sum_{z' \in \mathcal{L} \oplus \text{Vect}(y)} [z'] \in k_d P_\beta(V) \quad \text{and} \quad \sum_{z'' \in \mathcal{L} \oplus \text{Vect}(y')} [z''] \in k_d P_\beta(V),
\]

hence \( f_d \otimes \text{iso}_\alpha(v) = 0 \).

We have the following result.

Proposition 5.5. (1) There exists a monomorphism \( i_d \) from \( k_d \Sigma_{\alpha,1} \) to \( k_d P_\beta \otimes \text{iso}_\alpha \).

(2) There exists a natural map:

\[ k_d \Sigma_{\alpha,1}/k_{d+1} \Sigma_{\alpha,1} \rightarrow \Lambda^{d+1} \otimes \text{iso}_\alpha \]

induced by \( i_d : k_d \Sigma_{\alpha,1} \rightarrow k_d P_\beta \otimes \text{iso}_\alpha \).

Proof. The first point is a direct consequence of Lemma 5.4 and the short exact sequence (4.8.1).

We deduce the second point from the following commutative diagram given by the first point and from the short exact sequence (4.8.2).

\[
\begin{array}{ccccccccc}
0 & \rightarrow & k_{d+1} \Sigma_{\alpha,1} & \rightarrow & k_d \Sigma_{\alpha,1} & \rightarrow & (k_d \Sigma_{\alpha,1}/k_{d+1} \Sigma_{\alpha,1}) & \rightarrow & 0 \\
& & i_{d+1} & \downarrow & i_d & & & \downarrow & \\
0 & \rightarrow & k_{d+1} P_\beta \otimes \text{iso}_\alpha & \rightarrow & k_d P_\beta \otimes \text{iso}_\alpha & \rightarrow & \Lambda^{d+1} \otimes \text{iso}_\alpha & \rightarrow & 0
\end{array}
\]

Hence, to obtain the composition factors of the functors \( \text{Mix}_{\alpha,1} \) we study the functors \( \Lambda^n \otimes \text{iso}_\alpha \) in the following section.

Remark 5.6. As a consequence of Theorem 7.1, we obtain that the natural map \( k_d \Sigma_{\alpha,1}/k_{d+1} \Sigma_{\alpha,1} \rightarrow \Lambda^{d+1} \otimes \text{iso}_\alpha \) is a monomorphism.

To conclude this section, we prove that the functors \( \text{Mix}_{\alpha,1} \) are infinite. For this, we need the following lemma.
Lemma 5.7. Let $V$ be an object in $\mathcal{T}_q$ of dimension greater than $d + 1$, such that $\Sigma_{a,1}(V) \neq \{0\}$. If $\{y, y'\}$ is a canonical generator of $\Sigma_{a,1}(V)$ and $v_1, \ldots, v_d$, be $d$ linearly independent elements in $\text{Vect}(y, y')$, then:

$$(g_d \otimes \text{iso}_a) \circ i_d \left( \sum_{z \in \text{Vect}(v_1, \ldots, v_d)} [(y + z, y' + z)] \right) = v_1 \wedge \ldots \wedge v_d \wedge (y + y') \otimes [h]$$

where $i_d$ is the monomorphism from $k_d \Sigma_{a,1}$ to $k_d P_\beta \otimes \text{iso}_a$ defined in the first point of Proposition 5.8 and $h$ the element of $\text{Hom}_{\mathcal{F}_\text{quad}}((x, \alpha), V)$ such that $h(x) = y + y'$.

Proof. We have, by definition of $i_d$ and $g_d \otimes \text{iso}_a$,

$$(g_d \otimes \text{iso}_a) \circ i_d \left( \sum_{z \in \text{Vect}(v_1, \ldots, v_d)} [(y + z, y' + z)] \right)
= (g_d \otimes \text{iso}_a)(\sum_{z \in \text{Vect}(v_1, \ldots, v_d)} ([y + z] + [y' + z]) \otimes [h])
= (v_1 \wedge \ldots \wedge v_d \wedge y + v_1 \wedge \ldots \wedge v_d \wedge y') \otimes [h]
= v_1 \wedge \ldots \wedge v_d \wedge (y + y') \otimes [h]$$

We deduce the following result.

Proposition 5.8. The functors $\text{Mix}_{a,1}$ are infinite.

Proof. It is sufficient to prove that the quotients of the filtration of $\Sigma_{a,1}$ are nonzero. For an object $V$ in $\mathcal{T}_q$ of dimension greater than $d$, the space $\Sigma_{1,1}(H_0 \perp V)$ contains the nonzero element $\{[a_0, b_0]\}$. Hence, the element of $k_d \Sigma_{1,1}(H_0 \perp V)$

$$x = \sum_{z \in \text{Vect}(v_1, \ldots, v_d)} [(a_0 + z, b_0 + z)]$$

verifies

$$(g_d \otimes \text{iso}_a) \circ i_d (x) = v_1 \wedge \ldots \wedge v_d \wedge (a_0 + b_0) \otimes [h] \neq 0$$

by Lemma 5.7. Consequently, $(g_d \otimes \text{iso}_a) \circ i_d (k_d \Sigma_{1,1}) \neq \{0\}$ and, by the commutativity of the diagram (5.5.1) given in the proof of the second point of Proposition 5.5 we have $k_d \Sigma_{1,1}/k_{d+1} \Sigma_{1,1} \neq \{0\}$.

In the same way, by considering the element

$$\sum_{z \in \text{Vect}(v_1, \ldots, v_d)} [(a_0 + z, a_0 + b_0 + z)] \in k_d \Sigma_{0,1}(H_0 \perp V),$$

we show: $k_d \Sigma_{0,1}/k_{d+1} \Sigma_{0,1} \neq \{0\}$.

6. Structure of the functors $\Lambda^n \otimes \text{iso}_a$

By the second point of Proposition 5.5 there exists a natural map from the subquotients $k_d \Sigma_{a,1}/k_{d+1} \Sigma_{a,1}$ of the filtration of the functor $\Sigma_{a,1}$ by the functors $k_d \Sigma_{a,1}$ to the functors $\Lambda^{d+1} \otimes \text{iso}_a$. The aim of this section is to study the functors $\Lambda^n \otimes \text{iso}_a$ in order to obtain the composition factors of the functors $\Sigma_{a,1}$. It is divided into two subsections: the first concerns the decompositions of the functors $\Lambda^n \otimes \text{iso}_a$ by the functors denoted by $L^n_{\alpha}$, and the second concerns the simplicity of the functors $L^n_{\alpha}$.
6.1. **Decomposition.** In order to identify the composition factors of the functor \( \Lambda^n \otimes \text{Iso}_\alpha \), we define the following morphisms of \( \mathcal{F}_{\text{quad}} \).

**Lemma 6.1.** (1) For an object \( V \) in \( T_q \), the linear maps
\[
\mu_V : \text{iso}_\alpha(V) \to (\Lambda^1 \otimes \text{iso}_\alpha)(V)
\]
defined by:
\[
\mu_V([(x, \alpha) \xrightarrow{h} V]) = h(x) \otimes [(x, \alpha) \xrightarrow{h} V]
\]
for a canonical generator \([(x, \alpha) \xrightarrow{h} V]\) in \( \text{iso}_\alpha(V) \), give rise to a monomorphism \( \mu : \text{iso}_\alpha \to \Lambda^1 \otimes \text{iso}_\alpha \) of \( \mathcal{F}_{\text{quad}} \).

(2) For an object \( V \) in \( T_q \), the linear maps
\[
\nu_V : (\Lambda^1 \otimes \text{iso}_\alpha)(V) \to \text{iso}_\alpha(V)
\]
defined by:
\[
\nu_V(w \otimes [(x, \alpha) \xrightarrow{h} V]) = B(w, h(x))[(x, \alpha) \xrightarrow{h} V]
\]
for a canonical generator \([(x, \alpha) \xrightarrow{h} V]\) in \( \text{iso}_\alpha(V) \), give rise to an epimorphism \( \nu : \Lambda^1 \otimes \text{iso}_\alpha \to \text{iso}_\alpha \) of \( \mathcal{F}_{\text{quad}} \).

**Proof.** (1) We check the commutativity of the following diagram, for a morphism \( T = [V \xleftarrow{f} X \xrightarrow{g} W] \) of \( \text{Hom}_{T_q}(V,W) \):
\[
\begin{array}{ccc}
\text{iso}_\alpha(V) & \xrightarrow{\mu_V} & (\Lambda^1 \otimes \text{iso}_\alpha)(V) \\
\text{iso}_\alpha(T) \downarrow & & \downarrow (\Lambda \otimes \text{iso}_\alpha)(T) \\
\text{iso}_\alpha(W) & \xrightarrow{\mu_W} & (\Lambda^1 \otimes \text{iso}_\alpha)(W).
\end{array}
\]

For a canonical generator \([(x, \alpha) \xrightarrow{h} V]\) of \( \text{iso}_\alpha(V) \), we denote by \( P \) the pullback of \( (x, \alpha) f \xrightarrow{h} X \xrightarrow{g} W \). If \( P = (x, \alpha) \), we denote by \( h' \) the morphism making the following diagram commutative:
\[
\begin{array}{ccc}
(x, \alpha) & \xrightarrow{h'} & W \\
\downarrow 1_\alpha & & \downarrow g \\
(x, \alpha) & \xrightarrow{h} & V & \xrightarrow{f} & X.
\end{array}
\]

We have
\[
(\Lambda^1 \otimes \text{iso}_\alpha)(T) \circ \mu_V([(x, \alpha) \xrightarrow{h} V]) = (\Lambda^1 \otimes \text{iso}_\alpha)(T)(h(x) \otimes [(x, \alpha) \xrightarrow{h} V])
\]
\[
= \begin{cases} 
p_g \circ f \circ h(x) \otimes [(x, \alpha) \xrightarrow{h'} W] & \text{if } P = (x, \alpha) \\
0 & \text{otherwise}
\end{cases}
\]

and
\[
\mu_W \circ \text{iso}_\alpha(T)([(x, \alpha) \xrightarrow{h} V]) = \mu_W \begin{cases} 
[(x, \alpha) \xrightarrow{h'} W] & \text{if } P = (x, \alpha) \\
0 & \text{otherwise}
\end{cases}
\]
\[
= \begin{cases} 
h'(x) \otimes [(x, \alpha) \xrightarrow{h'} W] & \text{if } P = (x, \alpha) \\
0 & \text{otherwise}
\end{cases}.
\]
By commutativity of the previous cartesian diagram, we have \( g \circ h' = f \circ h \) hence, by composition with \( p_g \), we obtain: \( h' = p_g \circ f \circ h \). Consequently, the linear maps \( \mu_V \) give rise to a nonzero natural map \( \mu : \text{iso} \to \Lambda^1 \otimes \text{iso} \). We deduce from the simplicity of the functors \( \text{iso} \) given in Corollary \ref{cor18} that the natural map \( \mu \) is a monomorphism in \( F_{\text{quad}} \).

(2) We check the commutativity of the following diagram, for a morphism \( T = [V \xrightarrow{f} X \xrightarrow{g} W] \) of \( \text{Hom}_F(V, W) \):

\[
\begin{array}{ccc}
(\Lambda^1 \otimes \text{iso})(V) & \xrightarrow{\nu} & \text{iso}(V) \\
\downarrow & & \downarrow \\
(\Lambda \otimes \text{iso})(T) & \xrightarrow{\nu} & \text{iso}(T) \\
\downarrow & & \downarrow \\
(\Lambda^1 \otimes \text{iso})(W) & \xrightarrow{\nu} & \text{iso}(W).
\end{array}
\]

With the same notations as above, we have:

\[
\text{iso}(T) \circ \nu_V(v \otimes [h]) = \text{iso}(T)(B(h(x), v)[h]) = \begin{cases} B(h(x), v)[h'] & \text{if } P \simeq \text{Vect}(x) \\ 0 & \text{otherwise.} \end{cases}
\]

and

\[
\nu_W \circ (\Lambda^1 \otimes \text{iso})(T)(v \otimes [h]) = \nu_W \begin{cases} p_g \circ f(v) \otimes [h'] & \text{if } P \simeq \text{Vect}(x) \\ 0 & \text{otherwise.} \end{cases}
\]

We have:

\[
B(h(x), v) = B(f \circ h(x), f(v)) \quad \text{since } f \text{ preserves quadratic forms}
\]

\[
= B(g \circ h'(x), f(v)) \quad \text{by commutativity of the cartesian diagram}
\]

\[
= B(g \circ h'(x), g \circ p_g \circ f(v)) \quad \text{by orthogonality of } W \text{ and } L
\]

\[
= B(h'(x), p_g \circ f(v)) \quad \text{since } g \text{ preserves quadratic forms}.
\]

Hence, the linear maps \( \nu_W \) define a natural map \( \nu : \Lambda^1 \otimes \text{iso} \to \text{iso} \), which is clearly nonzero. We deduce from the simplicity of the functors \( \text{iso} \) given in Corollary \ref{cor18} that \( \nu \) is an epimorphism of \( F_{\text{quad}} \).

\[\square\]

The natural maps \( \mu \) and \( \nu \) defined in the previous lemma allow us to define the following morphisms in \( F_{\text{quad}} \).

**Definition 6.2.** Let \( n \) be a non-negative integer.

1. The natural map \( \mu_n : \Lambda^n \otimes \text{iso} \to \Lambda^{n+1} \otimes \text{iso} \) is obtained by the following composition

\[
\Lambda^n \otimes \text{iso} \xrightarrow{1 \otimes \mu} \Lambda^n \otimes \Lambda^1 \otimes \text{iso} \xrightarrow{m \otimes 1} \Lambda^{n+1} \otimes \text{iso}
\]

where \( m : \Lambda^n \otimes \Lambda^1 \to \Lambda^{n+1} \) is the product in the exterior algebra.

2. The natural map \( \nu_n : \Lambda^{n+1} \otimes \text{iso} \to \Lambda^n \otimes \text{iso} \) is obtained by the following composition

\[
\Lambda^{n+1} \otimes \text{iso} \xrightarrow{\Delta \otimes 1} \Lambda^n \otimes \Lambda^1 \otimes \text{iso} \xrightarrow{1 \otimes \nu} \Lambda^n \otimes \text{iso}
\]

where \( \Delta : \Lambda^{n+1} \to \Lambda^n \otimes \Lambda^1 \) is the coproduct.

We have the following proposition.
Proposition 6.3. The following sequence is an exact complex.

$$\ldots \rightarrow \Lambda^n \otimes \text{iso}_\alpha \xrightarrow{\mu_n} \Lambda^{n+1} \otimes \text{iso}_\alpha \xrightarrow{\mu_{n+1}} \Lambda^{n+2} \otimes \text{iso}_\alpha \rightarrow \ldots$$

Proof. We prove, according to the definition, that the kernel of \((\mu_{n+1})_V\) is the vector space generated by the set

\[\{v_1 \land \ldots \land v_n \land h(x) \otimes [h] \mid [h] \text{ a generator of iso}_\alpha(V) \text{ and } v_1, \ldots, v_n \text{ elements in } V\}\]

and this space coincide with the image of \((\mu_n)_V\). \(\square\)

Proposition 6.3 justifies the introduction of the following functor.

Definition 6.4. The functor \(K_n^\alpha\) is the kernel of the map: \(\mu_n : \Lambda^n \otimes \text{iso}_\alpha \rightarrow \Lambda^{n+1} \otimes \text{iso}_\alpha\).

As observed in the proof of Proposition 6.3, we have the following characterization of the spaces \(K_n^\alpha(V)\).

Lemma 6.5. For an object \(V\) in \(\mathcal{T}_q\), the space \(K_n^\alpha(V)\) is generated by the following elements

\[z \land h(x) \otimes [h]\]

where \([h]\) is a canonical generator of the space \(\text{iso}_\alpha(V)\) and \(z\) is an element in \(\Lambda^{n-1}(V)\).

The result below is a straightforward consequence of Proposition 6.3.

Corollary 6.6. For \(n\) a nonzero integer, we have the short exact sequence:

$$0 \rightarrow K_n^\alpha \rightarrow \Lambda^n \otimes \text{iso}_\alpha \rightarrow K_{n+1}^\alpha \rightarrow 0.$$

Remark 6.7. We will prove, in a subsequent paper concerning the calculation of \(\text{Hom}_{\mathcal{F}_{\text{quad}}}(\Lambda^n \otimes \text{iso}_\alpha, \Lambda^m \otimes \text{iso}_\alpha)\) that this short exact sequence is not split.

We next explain how to decompose the functors \(K_n^\alpha\). We begin by investigating the case of the functor \(K_1^\alpha\).

Lemma 6.8. The functor \(K_1^\alpha\) is equivalent to the functor \(\text{iso}_\alpha\).

Proof. Let \(V\) be an object in \(\mathcal{T}_q\). A basis of the vector space \(K_1^\alpha(V)\) is given by the set of elements of the following form: \(h(x) \otimes [h]\) for \([h]\) a canonical generator of \(\text{iso}_\alpha(V)\). Then we define the linear map

\[K_1^\alpha(V) \xrightarrow{\sigma_V} \text{iso}_\alpha(V)\]

\[h(x) \otimes [h] \mapsto [h]\]

and we leave the reader to check that \(\sigma_V\) is an isomorphism and that these linear maps are natural. \(\square\)

In order to identify the composition factors of the functors \(K_n^\alpha\) for \(n > 1\), we need the following lemma.

Lemma 6.9. For \(n\) a nonzero integer, the morphism \(\nu_n : \Lambda^{n+1} \otimes \text{iso}_\alpha \rightarrow \Lambda^n \otimes \text{iso}_\alpha\) induces a morphism \(\nu_n^K : K_{n+1}^\alpha \rightarrow K_n^\alpha\) making the following diagram commute

\[\begin{array}{ccc}
K_{n+1}^\alpha & \xrightarrow{\nu_{n}^K} & K_n^\alpha \\
\downarrow & & \downarrow \\
\Lambda^{n+1} \otimes \text{iso}_\alpha & \xrightarrow{\nu_n} & \Lambda^n \otimes \text{iso}_\alpha.
\end{array}\]
Proof. For an object $V$ in $\mathcal{T}_q$ and $v_1 \ldots v_n \wedge h(x) \otimes [h]$ a generator of $K_n^{n+1}(V)$, we have:

$$(\nu_{nV})(v_1 \ldots v_n \wedge h(x) \otimes [h])$$

$$= \left( \sum_{i=1}^{n} v_i \otimes B(v_i, h(x)) [h] \right) + v_1 \otimes B(h(x), h(x)) [h].$$

Since $B$ is alternating, we have $B(h(x), h(x)) = 0$. Hence,

$$(\nu_{nV})(v_1 \ldots v_n \wedge h(x) \otimes [h]) = \sum_{i=1}^{n} v_i \otimes B(v_i, h(x)) [h] \in K_n^n(V).$$

We deduce the existence of the induced morphism $\nu_n^K$. \hfill \Box

This lemma justifies the introduction of the following definition.

**Definition 6.10.** For $n \geq 2$ an integer, let $L_n^r$ be the kernel of the morphism $\nu_n^{K^n-1} : K_n^n \rightarrow K_n^{n-1}$.

We have the following characterization of the spaces $L_n^n(V)$ which is useful below.

**Lemma 6.11.** For an object $V$ in $\mathcal{T}_q$, the space $L_n^n(V)$ is generated by the elements of the following form:

$$z \wedge h(x) \otimes [h],$$

where $[h]$ is a canonical generator of the space $\text{iso}_n(V)$ and $z$ is an element of $\Lambda^{n-1}(\text{Vect}(h(x))^\perp)$.

**Proof.** Let $V$ be an object in $\mathcal{T}_q$. Since the space $L_n^n(V)$ is a subvector space of $K_n^n(V)$, we deduce from Lemma 6.5 that the vector space $L_n^n(V)$ is generated by the elements of the following form: $z \wedge h(x) \otimes [h]$.

For a given canonical generator $[h]$ of $\text{iso}_n(V)$, since the quadratic space $V$ is nondegenerate, there is an element $w$ in $V$ such that

$$B(h(x), w) = 1.$$ 

Let $W$ be the space $\text{Vect}(h(x), w)$ and $V \simeq W \perp W^\perp$ be an orthogonal decomposition of the space $V$. The canonical generator $z \wedge h(x) \otimes [h]$ of $K_n^n(V)$ can be written in the following form:

$$z' \wedge h(x) \otimes [h] + z'' \wedge w \wedge h(x) \otimes [h]$$

where $z' \in \Lambda^{n-1}(W^\perp)$ and $z'' \in \Lambda^{n-2}(W^\perp)$.

Let $x$ be an element of $L_n^n(V)$. Then:

$$x = \sum_{[h] \in \mathcal{G}(\text{iso}_n(V))} z_h \wedge h(x) \otimes [h] = \sum_{[h] \in \mathcal{G}(\text{iso}_n(V))} (z'_h \wedge h(x) \otimes [h] + z''_h \wedge w \wedge h(x) \otimes [h])$$

where $\mathcal{G}(\text{iso}_n(V))$ is the set of the canonical generators of $\text{iso}_n(V)$. Consequently,

$$\nu_{n-1}^{K^n}(z'_h \wedge h(x) \otimes [h]) = 0$$

since $z'_h \in \Lambda^{n-1}(W^\perp) \subset \Lambda^{n-1}(\text{Vect}(h(x))^\perp)$ and

$$\nu_{n-1}^{K^n}(z''_h \wedge w \wedge h(x) \otimes [h]) = z''_h \wedge h(x) \otimes [h].$$

Since the element $x$ is in the kernel of $\nu_{n-1}^{K^n}$, we deduce that $z''_h = 0$. Hence

$$x = \sum_{[h] \in \mathcal{G}(\text{iso}_n(V))} z'_h \wedge h(x) \otimes [h]$$
Proof. By Lemma 6.9, the following diagram is commutative:

\[ \begin{array}{ccc}
\Lambda^{n+2} \otimes \text{iso}_\alpha & \xrightarrow{\nu_{n+1}} & \Lambda^{n+1} \otimes \text{iso}_\alpha \\
\downarrow \text{iso} & & \downarrow \text{iso} \\
\Lambda^n & \xrightarrow{\nu_n} & \Lambda^{n-1} \otimes \text{iso}_\alpha.
\end{array} \]

Lemma 6.12. The composition: \( \Lambda^{n+2} \otimes \text{iso}_\alpha \xrightarrow{\nu_{n+1}} \Lambda^{n+1} \otimes \text{iso}_\alpha \xrightarrow{\nu_n} \Lambda^n \otimes \text{iso}_\alpha \) is zero.

Proof. Let \( V \) be an object in \( T_q \) and \( v_1 \wedge \ldots \wedge v_{n+2} \otimes [h] \) be an element of \( \Lambda^{n+2} \otimes \text{iso}_\alpha(V) \). Then

\[
\nu_n \circ \nu_{n+1}(v_1 \wedge \ldots \wedge v_{n+2} \otimes [h]) = \nu_n(\sum_{i=1}^{n+2} v_i \wedge \ldots \wedge \hat{v}_i \wedge \ldots \wedge v_{n+2} \otimes B(v_i, h(x))[h])
\]

\[
= \sum_{j \neq i} \sum_{i=1}^{n+2} (v_1 \wedge \ldots \wedge \hat{v}_i \wedge \ldots \wedge v_j \wedge \ldots \wedge v_{n+2} \otimes B(v_i, h(x))B(v_j, h(x))[h])
\]

\[= 0 \]

since the characteristic is equal to 2. \( \square \)

We deduce the following result.

Lemma 6.13. The map \( \nu_n^K : K_{\alpha}^{n+1} \rightarrow K_{\alpha}^n \) factors through \( L_{\alpha}^n \).

Proof. By Lemma 6.9, the following diagram is commutative:

\[ \begin{array}{ccc}
K_{\alpha}^{n+1} & \xrightarrow{\nu_n^K} & K_{\alpha}^n \\
\downarrow \nu_{n+1} & & \downarrow \nu_{n-1} \\
\Lambda^{n+1} & \xrightarrow{\nu_n} & \Lambda^{n-1} \otimes \text{iso}_\alpha.
\end{array} \]

Consequently, we deduce from Lemma 6.12 that \( \nu_{n-1} \circ \nu_n^K = 0 \). Hence, there is a morphism \( \tilde{\nu}_n^K : K_{\alpha}^{n+1} \rightarrow L_{\alpha}^n \) making the following diagram commutative

\[ \begin{array}{ccc}
K_{\alpha}^{n+1} & \xrightarrow{\nu_n^K} & K_{\alpha}^n \\
\downarrow \nu_{n-1} & & \downarrow \nu_{n-1} \\
L_{\alpha}^n = \text{Ker}(\nu_{n-1}) & \rightarrow & K_{\alpha}^n \rightarrow K_{\alpha}^{n-1}.
\end{array} \]

\( \square \)

Then, we have the following proposition.

Proposition 6.14. For \( n \) a nonzero integer, there is a short exact sequence:

\[ 0 \rightarrow L_{\alpha}^{n+1} \rightarrow K_{\alpha}^{n+1} \rightarrow L_{\alpha}^n \rightarrow 0. \]

Proof. It is sufficient to prove that the natural map \( \tilde{\nu}_n^K : K_{\alpha}^{n+1} \rightarrow L_{\alpha}^n \) constructed in the proof of the previous Lemma is an epimorphism of \( F_{\text{quad}} \).

Let \( V \) be an object in \( T_q \) and let \( v_1 \wedge \ldots \wedge v_{n-1} \wedge h(x) \otimes [h] \) be a generator of \( L_{\alpha}^n(V) \). By definition of \( L_{\alpha}^n(V) \) we have \( B(v_i, h(x)) = 0 \) for all \( i \) in \( \{1, \ldots, n-1\} \). Since \( h(x) \) is a nonzero element in the nondegenerate quadratic space \( V \), there is an element \( v \) in \( V \) such that \( B(v, h(x)) = 1 \). Then, we prove that the element

\[ v_1 \wedge \ldots \wedge v_{n-1} \wedge v \wedge h(x) \otimes [h] \]

in \( K_{\alpha}^{n+1}(V) \) verifies

\[ (\tilde{\nu}_n^K)_V(v_1 \wedge \ldots \wedge v_{n-1} \wedge v \wedge h(x) \otimes [h]) = v_1 \wedge \ldots \wedge v_{n-1} \wedge h(x) \otimes [h]. \]

Hence, \( \tilde{\nu}_n^K \) is surjective. \( \square \)
Remark 6.15. Proposition 6.14 is equivalent to the following statement: the complex
\[ \ldots \rightarrow K_{n+1}^{\alpha} \xrightarrow{\nu^K} K_{n}^{\alpha} \xrightarrow{\nu^{K-1}} K_{n-1}^{\alpha} \rightarrow \ldots \]
is exact.

6.2. Simplicity of the functors \( L^{n}_{\alpha} \). In this section, we prove the following result, where the functors \( L^{n}_{\alpha} \) are the subfunctors of \( \Lambda^n \otimes \text{iso}_{\alpha} \) defined in Definition 6.10.

**Theorem 6.16.** The functors \( L^{n}_{\alpha} \) are simple.

To prove this theorem, we need the following fundamental lemma.

**Lemma 6.17.** If \( J \) is a subfunctor of \( L^{n}_{\alpha} \), then for all object \( V \) in \( T_q \), either \( J(V) = \{0\} \), or \( J(V) = L^{n}_{\alpha}(V) \).

**Proof.** Let \( J \) be a subfunctor of \( L^{n}_{\alpha} \) and \( V \) be an object in \( T_q \). Suppose that \( J(V) \neq \{0\} \) and denote by \( y \) a nonzero element of \( J(V) \). We have
\[ y = \sum_{[h] \in G(\text{iso}_{\alpha}(V))} z_h \wedge h(x) \otimes [h] \]
where \( z_h \) is an element of \( \Lambda^{n-1}(\text{Vect}(h(x))) \) by Lemma 6.11 and \( G(\text{iso}_{\alpha}(V)) \) is the set of canonical generators of the space \( \text{iso}_{\alpha}(V) \).

The proof is divided into three steps; in the first one we prove that there exists a generator \([h]\) of \( \text{iso}_{\alpha}(V) \) such that \( z_h \wedge h(x) \otimes [h] \in J(V) \). We deduce, in the second part, that for all other generator \([h']\) of \( \text{iso}_{\alpha}(V) \) we have a nonzero element of the form \( z' \wedge h'(x) \otimes [h'] \) in \( J(V) \). Finally, we prove that for each element of the form \( v_1 \wedge \ldots \wedge v_{n-1} \wedge h(x) \otimes [h] \) and each canonical generator \([h]\) of \( \text{iso}_{\alpha}(V) \), the element \( v_1 \wedge \ldots \wedge v_{n-1} \wedge h(x) \otimes [h] \) belongs to \( J(V) \). This will prove that the two spaces \( J(V) \) and \( L^{n}_{\alpha}(V) \) are isomorphic, by the characterization of the space \( L^{n}_{\alpha}(V) \) given in Lemma 6.11.

1. Let \([h]\) be a canonical generator of \( \text{iso}_{\alpha}(V) \) such that, in the decomposition of \( y \) given in (6.17.1), the element \( z_h \wedge h(x) \otimes [h] \) is nonzero. Since the space \( V \) is nondegenerate, there exists an element \( v \) in \( V \) such that \( B(v, h(x)) = 1 \). We deduce a symplectic decomposition of \( V \) of the following form:
\[ V = \text{Vect}(h(x), v) \perp \text{Vect}(v_1, w_1) \perp \ldots \perp \text{Vect}(v_m, w_m) = \text{Vect}(h(x), v) \perp V' \]

We consider the morphism of \( \mathcal{E}_q \):
\[
\begin{align*}
f : & \quad V \rightarrow V \perp (H_0)^{\perp(2m+1)} \\
& \quad h(x) \mapsto h(x) \\
v & \mapsto v + a_0^{k+1} \\
v_k & \mapsto v_k + a_0^{2k} \\
w_k & \mapsto w_k + a_0^{2k+1}
\end{align*}
\]
for \( k \) an integer between 1 and \( m \), which allows us to define the following morphism in \( T_q \): \( T = [V \xrightarrow{f} V \perp (H_0)^{\perp(2m+1)} \xrightarrow{\perp} V] \). We deduce from
the two cartesian diagrams below:

\[ \begin{array}{ccc}
(x, \alpha) & \xrightarrow{\text{Id}} & V \\
\downarrow & & \downarrow \\
(h, x) & \xrightarrow{f} & V \perp (H_0)^{1/2(m+1)} \\
\end{array} \]

and, for \( h \neq h_i \),

\[ \begin{array}{ccc}
\{0\} & \xrightarrow{\text{Id}} & V \\
\downarrow & & \downarrow \\
(h_i, x) & \xrightarrow{f} & V \perp (H_0)^{1/2(m+1)} \\
\end{array} \]

that \( J(T)(y) = z_h \land h(x) \otimes [h] \in J(V) \), since \( \epsilon(T) = \text{Id}_V \).

(2) Let \( [h'] \) be a canonical generator of \( \text{iso}_\alpha(V) \) different from \([h]\). We have \( q(h'(x)) = q((h(x)) = \alpha \), hence the linear isomorphism denoted by \( f \) from \((h(x), \alpha)\) to \((h'(x), \alpha)\) is a morphism in \( E_{\deg q} \). So, we can apply Theorem \( \ref{thm:existence} \) to obtain the existence of a morphism \( f \) of \( \text{Hom}_{E_\alpha}(V, V) \) making the following diagram commutative:

\[ \begin{array}{ccc}
V & \xrightarrow{f} & V \\
\downarrow & & \downarrow \\
(h(x), \alpha) & \xrightarrow{f} & (h'(x), \alpha). \\
\end{array} \]

We deduce the following cartesian diagram:

\[ \begin{array}{ccc}
(x, \alpha) & \xrightarrow{h'} & V \\
\downarrow & & \downarrow \text{Id} \\
(h, x) & \xrightarrow{f} & V. \\
\end{array} \]

Consequently, by the consideration of the morphism \( T = [V \xrightarrow{f} V \xleftarrow{\text{Id}} V] \), we obtain:

\[ J(T)(z_h \land h(x) \otimes [h]) = \Lambda^{n-1}(f)(z_h) \land h'(x) \otimes [h'] \in J(V). \]

(3) By the point (1) of the proof, there exists a nonzero element of the form \( z \land h(x) \otimes [h] \) in \( J(V) \). We want to prove that, for each element of the form \( v_1 \land \ldots \land v_{n-1} \in \Lambda^{n-1}(\text{Vect}(h(x))^{1}) \) and each canonical generator \([h]\) of \( \text{iso}_\alpha(V) \), the element \( v_1 \land \ldots \land v_{n-1} \land h(x) \otimes [h] \) belongs to \( J(V) \). According to the proof of Lemma \( \ref{lemma:existence} \) it is sufficient to prove that the element \( v_1 \land \ldots \land v_{n-1} \land h(x) \otimes [h] \) belongs to \( J(V') \) for \( v_1 \land \ldots \land v_{n-1} \in \Lambda^{n-1}(V') \) where \( V' \) is the space considered in the decomposition \( \ref{decomp} \). By simplicity of the functor \( \Lambda^{n-1} \) in \( F \), we have the existence of an endomorphism \( g \) of \( \epsilon(V') \) such that

\[ \Lambda^{n-1}(g)(z) = v_1 \land \ldots \land v_{n-1}. \]
We deduce that
\[ J(\text{Id}_{\mathcal{T}_q}(\text{Vect}(h(x), v)) \perp t_g)(z \wedge h(x) \otimes [h]) = v_1 \wedge \ldots \wedge v_{n-1} \wedge h(x) \otimes [h] \]
where \( t_g \) is an antecedent of \( g \in \text{End}_{\mathcal{E}}(\epsilon(V')) \) by the forgetful functor \( \epsilon : \mathcal{T}_q \to \mathcal{E} \) which is full by Proposition 3.5 in [13] and \( \text{Id}_{\mathcal{T}_q}(\text{Vect}(h(x), v)) \perp t_g \) is the orthogonal sum of the morphisms of \( \mathcal{T}_q \).

\[ \square \]

**Proof of Theorem 6.16.** Let \( J \) be a nonzero subfunctor of \( L_n^\alpha \) and \( V \) be an object in \( \mathcal{T}_q \) such that the space \( J(V) \) is nonzero. By Lemma 6.17 we have \( J(V) = L_n^\alpha(V) \).

We prove, in the following, that for all object \( W \) in \( \mathcal{T}_q \), \( J(W) = L_n^\alpha(W) \).

Let \( W \) be a fixed object in \( \mathcal{T}_q \). The proof is divided into two parts.

1. Let us prove that \( J(V \perp W) \simeq L_n^\alpha(V \perp W) \).

   Let \( i \) be the canonical inclusion from \( V \) to \( V \perp W \) and \( T = [V \overset{i}{\to} V \perp W \overset{\text{Id}}{\leftarrow} V \perp W] \) be the morphism of \( \mathcal{T}_q \). We have the following cartesian diagram:

   \[
   \begin{array}{ccc}
   (x, \alpha) & \xrightarrow{i \circ h} & V \perp W \\
   \downarrow \text{Id} & & \downarrow \text{Id} \\
   (x, \alpha) & \xrightarrow{h} & V \xleftarrow{i} V \perp W.
   \end{array}
   \]

   Since
   \[
   [V \perp W \overset{\text{Id}}{\to} V \perp W \overset{i}{\leftarrow} V] \circ [V \overset{i}{\to} V \perp W \overset{\text{Id}}{\leftarrow} V \perp W] = \text{Id}_V
   \]

   we deduce that the space \( J(V \perp W) \) is nonzero. Hence, by Lemma 6.17 we have \( J(V \perp W) \simeq L_n^\alpha(V \perp W) \).

2. Let us prove that \( J(W) \simeq L_n^\alpha(W) \).

   According to Lemma 6.17 it is sufficient to prove that if \( L_n^\alpha(W) \) is non trivial then \( J(W) \) is not zero. Let \( j \) be the canonical inclusion from \( W \) to \( V \perp W \).

   We deduce from
   \[
   [V \perp W \overset{\text{Id}}{\to} V \perp W \overset{j}{\leftarrow} W] \circ [W \overset{j}{\to} V \perp W \overset{\text{Id}}{\leftarrow} V \perp W] = \text{Id}_W
   \]

   the existence of the surjection: \( L_n^\alpha(V \perp W) \twoheadrightarrow L_n^\alpha(W) \). Furtermore, by the first point of the proof, we have \( J(V \perp W) = L_n^\alpha(V \perp W) \). This gives rise to the following commutative diagram:

   \[
   \begin{array}{ccc}
   J(V \perp W) & \xrightarrow{\simeq} & J(W) \\
   \downarrow & & \downarrow \\
   L_n^\alpha(V \perp W) & \xrightarrow{\simeq} & L_n^\alpha(W).
   \end{array}
   \]

Consequently, by a diagram chasing argument, we obtain that if \( L_n^\alpha(W) \) is nonzero then \( J(W) \) is nonzero.

\[ \square \]
Proposition 6.18. The functors in the union of the families \( \{L_0^n \mid n \in \mathbb{N}\} \) and \( \{L_1^n \mid n \in \mathbb{N}\} \) are pairwise non-isomorphic.

Proof. For a fixed \( \alpha \), there exists, for all integer \( n \), a minimal integer \( d(n) \) such that

\[
L_\alpha^n(H_0^{1,d(n)}) \neq 0.
\]

Let \( k \) be an integer different from \( n \), if \( |n - k| \geq 2 \), the integers \( d(n) \) and \( d(k) \) allow us to distinguish the simple functors \( L_\alpha^n \) and \( L_\alpha^k \), in the contrary case, we prove that the dimensions of the spaces \( L_\alpha^n(H_0^{1,d(n)}) \) and \( L_\alpha^k(H_0^{1,d(n)}) \) are different. This proves that the simple functors \( L_\alpha^n \) and \( L_\alpha^k \) are not isomorphic.

Furthermore, two simple functors \( S_1 \) and \( S_2 \) in \( \mathcal{F}_{quad} \) are not isomorphic if there exists a morphism \( T \) in \( T_q \) such that \( S_1(T) = 0 \) and \( S_2(T) \neq 0 \). Moreover, the morphisms \( T \) constructed in the first point of the proof of Lemma 6.17 verify

\[
L_\alpha^n(T) \neq 0 \quad \text{and} \quad L_\alpha^k(\alpha+1)(T) = 0
\]

where \((\alpha + 1)\) is the reduction mod 2 of \( \alpha + 1 \).

\[\square\]

7. The composition factors of the functors Mix\(_{0,1}\) and Mix\(_{1,1}\)

We prove in this section that the functors Mix\(_{0,1}\) and Mix\(_{1,1}\) are uniserial (i.e. the lattice of its subfunctors is totally ordered) and the composition factors of the functor Mix\(_{0,1}\) are the functors \( L_\alpha^0 \) and those of Mix\(_{1,1}\) are the functors \( L_\alpha^1 \). For that, we identify the subquotient \( k_d\Sigma_{\alpha,1}/k_{d+1}\Sigma_{\alpha,1} \) of the filtration of the functor \( \Sigma_{\alpha,1} \) by the functors \( k_d\Sigma_{\alpha,1} \) introduced in Proposition 5.2 with the functor \( L_\alpha^{d+1} \) defined in Definition 6.10. This gives rise to the following result.

Theorem 7.1. The functor \( \Sigma_{\alpha,1} \) is uniserial and its unique composition series is given by the decreasing filtration by the functors \( k_d\Sigma_{\alpha,1} \)

\[
\ldots \subset k_d\Sigma_{\alpha,1} \subset \ldots \subset k_1\Sigma_{\alpha,1} \subset k_0\Sigma_{\alpha,1} = \Sigma_{\alpha,1}
\]

which verifies:

\[
k_d\Sigma_{\alpha,1}/k_{d+1}\Sigma_{\alpha,1} \cong L_\alpha^{d+1}.
\]

Remark 7.2. Remark that the strategy of the following proof of the uniseriality of \( \Sigma_{\alpha,1} \) is close to the proof of Lemma 6.17

Proof. To prove that the functor \( \Sigma_{\alpha,1} \) is uniserial, it is sufficient to prove that if \( J \) is a nonzero subfunctor of \( \Sigma_{\alpha,1} \) then there exists an integer \( d \) such that \( J = k_d\Sigma_{\alpha,1} \).

Let \( V \) be an object in \( T_q \) such that \( J(V) \neq 0 \) and \( v \) be a nonzero element of \( J(V) \), we have:

\[
v = \sum_{(x,y) \in A_V} \alpha_{\{x,y\}}(v)[\{x,y\}]
\]

where \( A_V = \{\{x,y\} \mid x \in V, y \in V, q(x+y) = \alpha, B(x,y) = 1\} \). One verifies easily that for \( \{x,y\} \in A_V \) and \( l \in V \), \( \{x+l, y+l\} \in A_V \) if and only if \( l \in (Vect(x,y))^\perp \) or \( l = x+y+l' \) where \( l' \in (Vect(x,y))^\perp \). Since \( \{x+(x+y+l'), y+(x+y+l')\} = \{y+l', x+l'\} = \{x+l, y+l\} \) we obtain, after reordering:

\[
v = \sum_{i=1}^{n} \sum_{l \in L_i} \{\{x_i+l, y_i+l\}\}
\]

(7.2.1)
where \( \forall \{x_i, y_i\} \in A_V \), for \( i \neq j \), \( x_i + y_i \neq x_j + y_j \) and \( \mathcal{L}_i \) is a subvector space of \( \text{Vect}(x_i, y_i) \). We consider a vector space \( V' \), an element \( v' \) of \( J(V') \) and an element \( \{x', y'\} \) in \( A_V \) such that the dimension \( r' \) of \( \mathcal{L}' \) is minimal. We deduce from the decomposition 7.2.1 that \( J \subset k_{r'} \Sigma_{\alpha, 1} \).

To prove that \( k_{r'} \Sigma_{\alpha, 1} \subset J \), we consider the following decomposition of \( v' \) in \( V' \):

\[
v' = \sum_{l' \in \mathcal{L}'} \left( \sum_{j=1}^{p} \left[ \sum_{l \in \mathcal{L}_j} \{x_j + l, y_j + l\} \right] \right)
\]

where \( \forall j \), \( x_j + y_j \neq x' + y' \). By definition of \( \Sigma_{\alpha, 1} \) and \( \text{Mix}_{\alpha, 1} \), we have a natural map \( \sigma : J \to P_k \otimes \text{iso}_\alpha \) such that

\[
\sigma_{V'}(v') = \sum_{l' \in \mathcal{L}'} \left( \sum_{j=1}^{p} \left[ \sum_{l \in \mathcal{L}_j} \{x_j + l, y_j + l\} \right] \otimes [x' + y'] \right)
\]

where, by abuse, we denote by \( v \) the linear map \( \mathbb{F}_2 \to V \) determined by \( v \). Let \( f : \epsilon(V') \to \epsilon(V) \) be the linear map such that \( f(x' + y') = x' + y' \) and \( f(x_j + y_j) = x_j + y_j + m \) where \( m \) is a nonzero element of \( \mathcal{L}_j \). Since \( \epsilon \) is full by Proposition 3.5 in [13], we obtain the existence of a morphism \( T \) in \( \text{Hom}_{\mathcal{T}_q}(V', V') \) such that \( \epsilon(T) = f \). We deduce that

\[
(P_k \otimes \text{iso}_\alpha)(T)\sigma_V(v') = \sum_{l' \in \mathcal{L}'} \left( \sum_{j=1}^{p} \left[ \sum_{l \in \mathcal{L}_j} \{x_j + l, y_j + l\} \right] \otimes [x' + y'] \right)
\]

and, consequently

\[
J(T)(v') = \sum_{l' \in \mathcal{L}'} \left[ \{x' + l', y' + l'\} \right] \in J(V')
\]

where \( \mathcal{L}' \) is a subvector space of \( \text{Vect}(x', y') \) of dimension \( r' \).

Let \( W \) be an object of \( \mathcal{T}_q \), \( \sum_{l \in \mathcal{L}} [\{w_1 + l, w_2 + l\}] \), where \( \mathcal{L} \) is a subvector space of \( \text{Vect}(w_1, w_2) \) of dimension \( r' \), be a generator of \( k_{r'} \Sigma_{\alpha, 1}(W) \) and \( g : \epsilon(V') \to \epsilon(W) \) be the linear map such that \( g(x' + y') = w_1 + w_2 \) and \( g \) send a basis of \( \mathcal{L}' \) to a basis of \( \mathcal{L} \). By the fullness of \( \epsilon \) we obtain a morphism \( T' \) in \( \text{Hom}_{\mathcal{T}_q}(V', W) \) such that

\[
J(T')(\sum_{l' \in \mathcal{L}'} \left[ \{x' + l', y' + l'\} \right]) = \sum_{l \in \mathcal{L}} [\{w_1 + l, w_2 + l\}] \in J(W).
\]

Hence \( J = k_{r'} \Sigma_{\alpha, 1} \).

By Lemma 5.7, we have:

\[
(g_d \otimes \text{iso}_\alpha) \circ i_d(k_d \Sigma_{\alpha, 1}) \subset L^{d+1}_\alpha.
\]

Consequently, by the commutative diagram (6) given in the proof of the second point of Proposition 5.5, we have the natural map

\[
\sigma : k_d \Sigma_{\alpha, 1} / k_{d+1} \Sigma_{\alpha, 1} \to L^{d+1}_\alpha.
\]

Since the quotients \( k_d \Sigma_{\alpha, 1} / k_{d+1} \Sigma_{\alpha, 1} \) are nonzero by Proposition 5.8 and the functors \( L^{d+1}_\alpha \) are simple by Theorem 6.16, the natural map \( \sigma \) is an equivalence. \( \Box \)
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