Lecture 3

Chapter I: Categories and functors

There is a definition page on the Gaucho that has all the most basic definitions - objects, morphisms, compositions, etc.

If $f \in \mathrm{Hom}_C(A, B)$, we often write $A \xrightarrow{f} B$ even if f is not literally a map.

Example 0.1. 1. The category of all sets, Set. The object class consists of all sets, and the morphisms are just set maps.

2. The category of all topological spaces, Top. The object class consists of all topological spaces, and the morphisms are continuous functions.

3. The category of all groups, Grp. The object class consists of all groups, and the morphisms are group homomorphisms.

4. Let $(P, \leq)$ be a partially ordered set with a relation $\leq$ which is reflexive, antisymmetric, and transitive. Then we can make P into a category, whose objects are the elements of p, and for $u, s \in P$, $\mathrm{Hom}_P(u, s) = \begin{cases} (u,s) & u \leq s \\ \varnothing & u \not\leq s \end{cases}$. We define the composition $(s, t)(u, s) \stackrel{\text{def}}{=} (u, t)$.

5. The opposite category of a category C, C^{op}.

6. Let R be a ring. R-Mod is the category of left R modules. R-mod is the finitely generated R-modules, and similarly for Mod-R and mod-R, which are the right R-modules.

7. R-comp. The object class consists of complexes of left R-modules.

Let $\mathbb{A}, \mathbb{A}'$ be objects of R-comp. Note: it is problematic to say "$\mathbb{A}, \mathbb{A}' \in R$-comp, as R-comp is not a set!

Say $\mathbb{A} = \cdots \longrightarrow A_{n+1} \xrightarrow{d_{n+1}} A_n \xrightarrow{d_n} A_{n-1} \longrightarrow \cdots$, and similarly for $\mathbb{A}'$. An element of $\mathrm{Hom}_{R-comp}(\mathbb{A}, \mathbb{A}')$ will be a sequence of R-module homomorphisms $f_n : A_n \to A'_n$ which make the following diagram commute:

$$\begin{tikzcd}
\cdots \arrow[r] \arrow[d] & A_n \arrow[r, "d_n"] \arrow[d, "f_n"'] & A_{n-1} \arrow[r] \arrow[d, "f_{n-1}"] & \cdots \arrow[d] \\
\cdots \arrow[r] & A'_n \arrow[r, "d'_n"'] & A'_{n-1} \arrow[r] & \cdots
\end{tikzcd}$$

8. The category of rings Ring, whose obejcts are rings and whose morphisms are ring homomorphisms.

9. The category of $\mathbb{Z}$-modules is usually denoted Ab. This is also the category of Abelian groups, and is the prototypical example of an Abelian category.

Definition 0.1. A category $\mathcal{C}$ is called pre-additive if for all A, B objects of $\mathcal{C}$, the set $\mathrm{Hom}_{\mathcal{C}}(A, B)$ is an additive Abelian group (additive means we use the symbol "+") such that for all eligible morphisms f, g, h, k,

$$h(f+g) = hf + hg$$
$$(f+g)k = fk + gk$$

where "elibigle" means that these expressions make sense and are well-defined.

Example 0.2. 1. R-mod (in particular Ab)

2. R-comp

3. Ring fails to be pre-additive, because the identity morphisms add to be something which is not the identity morphism.

Definition 0.2. Let $\mathcal{C}, \mathcal{D}$ be categories. A functor $F : \mathcal{C} \to \mathcal{D}$ consists of an assignment $F_0 : \mathrm{Obj}(\mathcal{C}) \to \mathrm{Obj}(\mathcal{D})$, and for each pair of objects $A, B \text{``} \in \text{''} \mathrm{Obj}(\mathcal{C})$, a map (this actually is a map because we assume hom-sets are in fact sets). $F_{A,B} : \mathrm{Hom}_{\mathcal{C}}(A, B) \to \mathrm{Hom}_{\mathcal{D}}(F(A), F(B))$ such that, for all eligible morphisms $f, g$, and all $A \text{``} \in \text{''} \mathcal{C}$

(a) $F(\mathrm{Id}_A) = \mathrm{Id}_{F(A)}$

(b) $F(f \circ g) = F(f) \circ F(g)$

Example 0.3. 1. Let $\mathcal{C}$ be a category. Then we have the identity functor $\mathrm{Id}_{\mathcal{C}}$, which assigns $\mathrm{Id}_{\mathcal{C}}(A) = A$, and $\mathrm{Id}_{\mathcal{A}}(f) = f$ for any eligible $A \text{``} \in \text{''} \mathrm{Obj}(\mathcal{D})$ and morphisms f.

2. Functors $\pi_n : \mathsf{Top} \to \mathsf{Grp}$ which sends $X \mapsto \pi_n(X)$

3. $\mathbb{S} : \mathsf{Top} \to \mathbb{Z}$-comp, which sends $X \mapsto \mathbb{S}(X)$, which is a complex

$$\cdots \longrightarrow S_{n+1}(X) \xrightarrow{\partial_{n+1}} S_n(X) \xrightarrow{\partial_n} S_{n-1}(X) \xrightarrow{\partial_{n-1}} \cdots \longrightarrow S_0(x) \xrightarrow{\partial_0} 0$$

Let $\phi : X \to Y$ be continuous for $X, Y \text{``} \in \text{''} \mathsf{Top}$. Then $\mathbb{S}(\phi)_n : S_n(X) \to S_n(Y)$ is given by $\sigma \mapsto \phi \circ \sigma$, and we can extend this for σ an n-simplex of X.