

§1. Banach vector bundles over an analytic space

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Remark : This a particular case of the following proposition: if π and π' are two morphisms of which at least one is finite, then

$$\begin{array}{ccc} X & & Y \\ \pi \searrow & & \swarrow \pi' \\ & S & \end{array} \quad \mathcal{O}_{X \times_S Y} = \mathcal{O}_X \otimes_{\mathcal{O}_S} \mathcal{O}_Y.$$

We have proved that $\mathcal{O}_{W \times X}$ is $\mathcal{O}_W$ -flat, so by scalar extension $\mathcal{O}_{S \times X}$ is $\mathcal{O}_S$ flat.

Corollary : If X and S are two manifolds and $\pi : X \rightarrow S$ is a submersion, then π is flat.

III. PRIVILEGED POLYCYLINDERS

§ 1. Banach vector bundles over an analytic space

Let E be a Banach space and X an analytic space. We denote then by E_X the trivial bundle $X \times E$ over X .

To define bundle morphisms, we first define the sheaf $\mathcal{H}_X(E)$ of germs of analytic morphisms from X to E . If $U \subset \mathbb{C}^n$ is open, then the set $\mathcal{H}(U, E)$ of analytic morphisms from U into E consists of all functions $g : U \rightarrow E$ having at every point $x \in U$ a converging power series expansion.

Let now X' be a local model for X , i.e. X' is the support of the quotient sheaf $\mathcal{O}_U/J$, where $U \subset \mathbb{C}^n$ is open and J is a coherent sheaf of ideals of $\mathcal{O}_U$, then $\mathcal{H}_{X'}(E)$ is the sheaf associated to the presheaf $V \rightarrow \mathcal{H}(V, E)/J_V \cdot \mathcal{H}(V, E)$ ($V \subset U$, V -open).

Remark : If X' is reduced, the sections of $\mathcal{H}_{X'}(E)$ are just the functions from X' to E which are locally induced by analytic functions on open sets in U .

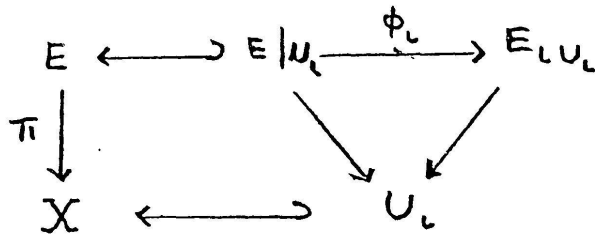
The sheaf $\mathcal{H}_X(E)$ is constructed with help of the local models X' of X , i.e. $\mathcal{H}_X(E)|X' = \mathcal{H}_{X'}(E)$, for every local model X' .

Definition 1 : The set of *analytic morphisms* from an analytic space X into a Banach space E is the set $\mathcal{H}(X; E)$ of sections of the sheaf $\mathcal{H}_X(E)$.

Let $\mathcal{L}(E, F)$ be the Banach space of all continuous linear mappings from the Banach space E into the Banach space F .

Definition 2 : An *analytic vector bundle morphism* from E_X into F_X is an analytic morphism from X into $\mathcal{L}(E, F)$.

Let E be a topological space, X an analytic space, and $\pi : E \rightarrow X$ a continuous projection.



Suppose that X has an open covering $(U_\iota)_{\iota \in I}$, and that for every $\iota \in I$ there is given a trivial Banach space bundle $E|_{U_\iota}$ and a homeomorphism ϕ_ι , such that the following diagram is commutative:

We suppose further that for each pair $\iota, \kappa \in I$ there is given an analytic vector bundle morphism $\gamma_{\iota\kappa} : E|_{U_\iota \cap U_\kappa} \rightarrow E|_{U_\iota \cap U_\kappa}$, with the underlying mapping $\phi_\iota \circ \phi_\kappa^{-1}$, such that:

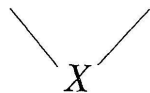
$$\gamma_{\iota\lambda} = \gamma_{\iota\kappa} \gamma_{\kappa\lambda}; \quad \gamma_{\iota\iota} = I, \quad \text{for all } \iota, \kappa, \lambda \in I.$$

This data gives a Banach vector bundle atlas on E and provides E with the structure of a Banach vector bundle over X (two atlases are equivalent if there exists an atlas containing both).

Remark: If X is reduced, the $\gamma_{\iota\kappa}$ are determined by their underlying map and the condition $\gamma_{\iota\lambda} = \gamma_{\iota\kappa} \gamma_{\kappa\lambda}$ is automatically satisfied.

Using local triviality, we can define morphisms for general Banach vector bundles.

Proposition 1: Let $\phi : E \rightarrow F$ be a morphism of two Banach vector



bundles E and F , and $x \in X$.

If $\phi_x \in \mathcal{L}(E(x), F(x))$ is an isomorphism, then there exists an open neighbourhood $U \subset X$ of x , such that $\phi|_U : E|_U \rightarrow F|_U$ is a vector bundle isomorphism.

Proof: First we take a trivialisation $E|_V = E_0|_V$, $F|_V = F_0|_V$ at $x \in V \subset X$ (V -open).

The set $\text{Isom}(E_0, F_0)$ of isomorphic mappings is an open subset of $\mathcal{L}(E_0, F_0)$ and the mapping $g \rightarrow g^{-1}$ is an analytic isomorphism:

$$\text{Isom}(E_0, F_0) \simeq \text{Isom}(F_0, E_0).$$

So we have in an open neighbourhood $U \subset X$ of x an analytic morphism $y \rightarrow \phi_y^{-1} \in \mathcal{L}(F_0, E_0)$, which defines the inverse morphism $(\phi|_U)^{-1} : F|_U \rightarrow E|_U$.

Definition 3 : Let E and F be two Banach spaces and f a continuous linear mapping from E into F . f is a *split mono-(epi) morphism*, if there exists a mapping $g \in \mathcal{L}(F, E)$ such that $g \circ f = I_E$. (Resp. $f \circ g = I_F$.)

Definirion 4 : Let E_1 and E_2 be two Banach vector bundles over an analytic space X , and f a vector bundle morphism from E_1 into E_2 . f is a *split mono (epi) morphism*, if there exists a vector bundle morphism $g : E_2 \rightarrow E_1$ such that $g \circ f = I_{E_1}$. (Resp. $f \circ g = I_{E_2}$.)

Equivalently, $f : E_1 \rightarrow E_2$ is a split monomorphism if and only if E_2 can

$$\begin{array}{c} \diagdown \quad \diagup \\ X \end{array}$$

be decomposed in a direct sum $E_2 = F_2 \oplus G_2$ such that

$$f : \begin{cases} E_1 \simeq F_2 \\ 0 \rightarrow G_2 \end{cases}.$$

and f is a split epimorphism if correspondingly

$$E_1 = F_1 \oplus G_1, \quad \text{such that} \quad f : \begin{cases} F_1 \rightarrow 0 \\ G_1 \simeq E_2 \end{cases}.$$

Proposition 2 : Let $E \xrightarrow{\phi} F$ be a bundle morphism and $x \in X$.

$$\begin{array}{c} \diagdown \quad \diagup \\ X \end{array}$$

If $\phi_x : E(x) \rightarrow F(x)$ is a split epi (mono) morphism, then the point x has an open neighbourhood $U \subset X$, such that $\phi|_U : E|_U \rightarrow F|_U$ is a split vector bundle epi (mono) morphism.

Proof : Suppose that ϕ_x is a split epimorphism. We take first a trivialisation $E|_V = E_{0V}$, $F|_V = F_{0V}$ at x , so that there exists a mapping $\sigma \in \mathcal{L}(F_0, E_0)$, $\phi_x \circ \sigma = I_{F_0}$. If we define a morphism $\psi : F_{0V} \rightarrow E_{0V}$ by $x \rightarrow \sigma \in \mathcal{L}(F_0, E_0)$, the morphism $\gamma = \phi \circ \psi : F_{0V} \rightarrow F_{0V}$ has an isomorphic fibre mapping $\gamma_x = I_{F_0}$ in x . By proposition 1 we have an isomorphic restriction $\gamma|_U$, $\phi|_U \circ (\psi|_U \circ (\gamma|_U)^{-1}) = I_{F_{0U}}$.

When ϕ_x is a split monomorphism, the proof is similar.

Definition 5 : Let B_1, B_2, B_3 be Banach spaces, and $j, k : B_1 \xrightarrow{j} B_2 \xrightarrow{k} B_3$ continuous linear mappings. This sequence forms a *complex*, if $k \circ j = 0$. This sequence is *split exact* if the space B_i can be decomposed in direct

sums $B_i = C_i \oplus D_i$ such that

$$j: \begin{cases} C_1 \rightarrow 0 \\ D_1 \simeq C_2 \end{cases} \quad k: \begin{cases} C_2 \rightarrow 0 \\ D_2 \simeq C_3 \end{cases}.$$

Definition 6: A Banach vector bundle morphism sequence

$$\begin{array}{ccccc} E_1 & \xrightarrow{f} & E_2 & \xrightarrow{g} & E_3 \\ & \searrow & \downarrow X & \swarrow & \\ & & X & & \end{array} \quad \text{is a complex if } g \circ f = 0.$$

The sequence is *split exact*, if every E_i can be decomposed $E_i = F_i \oplus G_i$, such that:

$$f: \begin{cases} F_1 \rightarrow 0 \\ G_1 \simeq F_2 \end{cases} \quad g: \begin{cases} F_2 \rightarrow 0 \\ G_2 \simeq F_3 \end{cases}.$$

Theorem 1: Let $\begin{array}{ccccc} E_1 & \xrightarrow{f} & E_2 & \xrightarrow{g} & E_3 \\ & \searrow & \downarrow X & \swarrow & \end{array}$ be a complex of Banach vector

bundles and $x_0 \in X$.

If the sequence of Banach spaces $E_1(x_0) \xrightarrow{f_{x_0}} E_2(x_0) \xrightarrow{g_{x_0}} E_3(x_0)$ is split exact, then there exists an open neighbourhood $U \subset X$ of x_0 , such that $E_1|_U \xrightarrow{f|_U} E_2|_U \xrightarrow{g|_U} E_3|_U$ is a split exact sequence of Banach vector bundles.

Proof: We take a neighbourhood V of x , such that we have a complex $E_{1V} \xrightarrow{f|_V} E_{2V} \xrightarrow{g|_V} E_{3V}$ of trivial bundles. By assumption we have the decompositions $E_{iV}(x_0) = F_i(x_0) \oplus G_i(x_0)$ with

$$f_{x_0}: \begin{cases} F_1(x_0) \rightarrow 0 \\ G_1(x_0) \simeq F_2(x_0) \end{cases} \quad g_{x_0}: \begin{cases} F_2(x_0) \rightarrow 0 \\ G_2(x_0) \simeq F_3(x_0) \end{cases}.$$

By proposition 2, $f|_V: G_{1V} \rightarrow E_{2V}$, $g|_V: G_{2V} \rightarrow E_{3V}$ are both split monomorphisms in a neighbourhood $W \subset V$ of x_0 and the images $F_2 = f(G_{1W})$, $F_3 = g(G_{2W})$ are subbundles of E_{2W} esp. E_{3W} , such that

$$E_{2W} = F_2 \oplus G_{2W}, \quad E_{3W} = F_3 \oplus G_{3W}.$$

By our construction

$$g|W : \begin{cases} F_2 \rightarrow 0 \\ G_2 W \simeq F_3 \end{cases}.$$

If $p: E_{2W} \rightarrow F_2$ is the projection with kernel G_{2W} , the map, $p \circ f: E_{1W} \rightarrow F_2$ is a split epimorphism in x_0 . Again by prop. 2 we have over an open neighbourhood $U \subset W$ of x_0 a decomposition $E_{1U} = F_1 \oplus G_{1U}$ (with $F_1 = \text{Ker } p \circ f$)

$$(p \circ f)|U : \begin{cases} F_1 \rightarrow 0 \\ G_{1U} \xrightarrow{\sim} F_{2U} \end{cases}.$$

The image $f|U(F_1)$ is contained in G_{2U} . But $g|U \circ f|U = 0$ and $g|G_{2U}$ is a monomorphism hence $f|U: F_1 \rightarrow 0$. We get finally (restricting all our morphisms to U)

$$f|U : \begin{cases} F_{1U} \rightarrow 0 \\ G_{1U} \simeq F_{2U} \end{cases} \quad g|U : \begin{cases} F_{2U} \rightarrow 0 \\ G_{2U} \xrightarrow{\sim} F_{3U} \end{cases}.$$

§ 2. Privileged polycylinders

Definition 1: A polycylinder in $\mathbb{C}^n$ is a compact set K of the form $K = K_1 \times \dots \times K_n$ where each K_i is a compact, convex subset of $\mathbb{C}$, with nonempty interior. If each K_i is a disc, then K is a polydisc. We first recall the following theorem of Cartan.

Theorem 1: Let K be a polycylinder contained in an open subset U of $\mathbb{C}^n$. Let $\mathcal{F}$ be a coherent analytic sheaf on U .

- (A) There exists an open neighbourhood of K over which $\mathcal{F}$ admits a finite free resolution

$$0 \rightarrow \mathcal{L}_n \rightarrow \dots \rightarrow \mathcal{L}_1 \rightarrow \mathcal{L}_0 \rightarrow \mathcal{F} \rightarrow 0.$$

- (B) $H^q(K, \mathcal{F}) = 0$ for $q > 0$.

(Reference: For instance Gunning and Rossi.)

We have the following consequences of this theorem:

- 1) Given a finite free resolution

$$0 \rightarrow \mathcal{L}_n \rightarrow \dots \rightarrow \mathcal{L}_1 \rightarrow \mathcal{L}_0 \rightarrow \mathcal{F} \rightarrow 0$$

of a coherent sheaf $\mathcal{F}$, the sequence