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Topological Tensor Products of Locally Convex Spaces

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Abstract – A locally convex, vector space is a couple (X,I) comprising of a vector space X and direct topology I on X, which is locally convex. A topological vector product is a speculation of the idea of a Banach space. The locally convex, spaces are experienced over and again while talking about powerless topologies on a Banach space, sets of administrators on Hilbert space, or the hypothesis of disseminations. This article skims the outside of this hypothesis, yet it will treat locally convex, spaces in detail as to empower the peruser to comprehend the utilization of these spaces in the three territories of examination.

Keywords: Convex Space, Locally Convex Space, Tensor Product.

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INTRODUCTION

In spite of the fact that the hypothesis of Banach spaces has been extremely prevalent among American mathematicians during the most recent twenty years, relatively little consideration appears to have been given, in this nation, to its speculations, aside from in the absolute most recent couple of years. Except for the remarkable work of [1,2], most commitments to the general hypothesis of locally convex spaces have been made by European mathematicians. There might be some intrigue, in this way, in a study in expansive layout of the latest advances in that field, some of which have not yet showed up in print. The vital inspiration driving the general hypothesis is simply equivalent to that of Banach: in particular, a quest for general instruments which may be applied effectively to useful investigation.

For obscure reasons, this noteworthy spearheading work has right up 'til the present time remained for all intents and purposes overlooked in this nation, regardless of its inherent significance and value. The other impact was applied by the improvements of the hypothesis of combination, and primarily through the endeavors to liberate that hypothesis from the shackles of the Carathéodory measure hypothesis and transform it into a minor section of the general hypothesis of topological vector spaces [3].

These endeavors finished in L. Schwartz's hypothesis of circulations (1945), which could be communicated distinctly in the language of locally convex vector spaces [4]; it worked out that for that hypothesis, Banach spaces were a totally deficient instrument, and the acknowledgment of that reality prompted exceptionally dynamic research on increasingly broad spaces, to which the vast majority of the outcomes got over the most recent couple of years owe their cause.

In practical investigation and related zones of arithmetic, locally convex, topological vector spaces or locally convex, spaces are instances of topological vector spaces (TVS) that sum up normed spaces. They can be characterized as topological vector spaces whose topology is produced by interpretations of adjusted, retentive, convex, sets. On the other hand they can be characterized as a vector space with a group of seminorms, and a topology can be characterized as far as that family. In spite of the fact that all in all such spaces are not really normable, the presence of a convex, nearby base for the zero vector is sufficient for the Hahn–Banach hypothesis to hold, yielding a sufficiently rich hypothesis of constant direct functionals.

Fréchet spaces are locally convex, spaces that are totally metrizable (with a decision of complete measurement). They are speculations of Banach spaces, which are finished vector spaces concerning a measurement created by a standard.

A topological vector space is a vector space that is additionally a topological space to such an extent that the straight structure and the topological structure are imperatively associated.

Definition. A topological vector space (TVS) is a vector space $\mathscr{X}$ together with a topology to such an extent that as for this topology

(a) the map of $\mathcal{X}$, $\mathcal{X} \longrightarrow \mathcal{X}$ defined by ($\mathscr{X}$, y) $\longrightarrow \mathscr{X}$ + y is continuous;

(b) the map of IF $\mathcal{X}$, $\mathcal{X} \longrightarrow \mathcal{X}$ defined by (α, $\mathscr{X}$) $\longrightarrow \alpha\mathscr{X}$ is continuous.

It is anything but difficult to see that a normed space is a TVS.

Suppose $\mathcal{X}$ is a vector space and $\wp$ is a family of seminorms on $\mathcal{X}$ Let. $\mathfrak{F}$ be the topology on $\mathcal{X}$ that has as a subbase the sets $\{x\colon\ p(x - x_0) < \varepsilon\}$, where $\wp \mathcal{E} \wp$, $\mathcal{X}_o$ $\mathcal{E}\mathcal{X}$ and $\mathcal{E}$ > O. Thus a subset $\mho$ of $\mathcal{X}$ is open if and only if for every $\mathcal{X}_o$ in $\mho$ there are $p_1, \ldots, p_n$ and $\varepsilon_1, \ldots, \varepsilon_n > 0$ such that $\bigcap_{i=1}^n \{x \in \mathscr{X}\colon\ p_i(x - x_0) < \varepsilon_i\} \subseteq U$ It is not difficult to show that $\mathcal{X}$ with this topology is a TVS.

Topologies from seminorms

Topologies given by means of seminorms on vectorspaces are depicted. These spaces are perpetually locally convex, in the feeling of having a nearby premise at 0 comprising of convex sets.

Let ϑ be a complex vectorspace. A seminorm υ on ϑ is a real-valued function on ϑ so that

$$\begin{cases} \nu(x) \geq 0 & \text{for all } x \in V & \textit{(non-negativity)} \\ \nu(\alpha x) = |\alpha| \cdot \nu(x) & \text{for all } \alpha \in \mathbb{C},\ x \in V & \textit{(homogeneity)} \\ \nu(x+y) \leq \nu(x) + \nu(y) & \text{for all } x, y \in V & \textit{(triangle inequality)} \end{cases}$$

We allow the situation that $\nu(x) = 0 \text{ yet } x \neq 0$. A pseudo-metric on a set ϑ is a real-valued function ***d*** on ***X*** x ***X*** so that

$$\begin{cases} d(x,y) \geq 0 & \textit{(non-negativity)} \\ d(x,y) = d(y,x) & \textit{(symmetry)} \\ d(x,z) \leq d(x,y) + d(x,z) & \textit{(triangle inequality)} \end{cases}$$

We allow $d(x,y) = 0$ for The associated pseudo-metric attached to the seminorm υ is

$$d(x,y) \;=\; \nu(x-y) \;=\; \nu(y-x)$$

This pseudometric is a measurement if and just if the seminorm is a standard.

Let $\{\nu_i : i \in I\}$ be a collection of semi-norms on a vectorspace ϑ with index set I. This family is a separating family of seminorms when for every $0 \neq \chi$ there is so that $\nu_i(x) \neq 0$

Claim

The collection of Φ all finite intersections of sets

$$U_{i,\varepsilon} \;=\; \{x \in V : \nu_i(x) < \varepsilon\} \qquad \text{(for } \varepsilon > 0 \text{ and } i \in I)$$

is a local basis at 0 for a locally convex topology.

Proof: As expected, we intend to denote a topological vector space topology on ϑ by saying a set ϑ is open if and only if for every $x \epsilon U$ there is some $N \epsilon \Phi$ so that

$$x + N \;\subset\; U$$

This would be the instigated topology related to the group of seminorms.

To start with, that we have a topology doesn't utilize the theory that the group of seminorms is isolating, despite the fact that focuses won't be shut without the isolating property. Subjective associations of sets containing 'neighborhoods' of the structure around each point x have a similar property. The vacant set and the entire space V are unmistakably 'open'. The least minor issue is to watch that limited crossing points of 'opens' are 'open'.

Taking a gander at each point x in a given limited crossing point, this adds up to watching that limited convergences of sets in Φ are again in Φ. Yet, Φ is deffined to be the assortment of every single limited crossing point of sets U i.e, so this works: we have conclusion under limited convergences, and we have a topology on V.

To confirm that this topology makes V a topological vectorspace, we should check the congruity of vector expansion and coherence of scalar increase, and shut ness of focuses. None of these checks is troublesome:

The isolating property suggests that the crossing point of the considerable number of sets with x+N with N ϵ U is simply x.

Given a point ϵ U , for each x≠y let Ux be an open set containing x however not y.Then

$$U = \bigcup_{x\neq y} U_x$$

is open and has supplement {y} , so the singleton set {y} is without a doubt shut.

To demonstrate congruity of vector expansion, it gets the job done to demonstrate that, given N ϵ Φ and given x, y ϵ V there are

$$(x+U)+(y+U') \subset x+y+N$$

The triangle inequality for semi-norms implies that for a fixed index i and for $\epsilon 1, \epsilon 2 > 0$

$$U_{i,\varepsilon_1} + U_{i,\varepsilon_2} \subset U_{i,\varepsilon_1+\varepsilon_2}$$

Then

$$(x+U_{i,\varepsilon_1})+(y+U_{i,\varepsilon_2}) \subset (x+y)+U_{i,\varepsilon_1+\varepsilon_2}$$

Thus, given

$$N = U_{i_1,\varepsilon_1} \cap \ldots \cap U_{i_n,\varepsilon_n}$$

Take

$$U = U' = U_{i_1,\varepsilon_1/2} \cap \ldots \cap U_{i_n,\varepsilon_n/2}$$

Demonstrating progression of the vector expansion.

For progression of scalar duplication, demonstrate that for given∝ ϵ k , x ϵ V , and N ϵ Φ there are δ>0 and U ϵ Φ so that

$$(\alpha+B_\delta)\cdot(x+U) \subset \alpha x+N \qquad (\text{with } B_\delta = \{\beta\in k : |\alpha-\beta|<\delta\})$$

Since N is a crossing point of the exceptional sub-premise sets U.i.ε, it does the trick to consider the case that N is such a set. Given α and x, for $|\alpha'-\alpha| < \delta$ and for $x - x' \in U_{i,\delta}$,

$$\begin{aligned}\nu_i(\alpha x-\alpha' x') &= \nu_i((\alpha-\alpha')x+(\alpha'(x-x')) \le \nu_i((\alpha-\alpha')x)+\nu_i(\alpha'(x-x'))\\ &= |\alpha-\alpha'|\cdot\nu_i(x)+|\alpha'|\cdot\nu_i(x-x') \le |\alpha-\alpha'|\cdot\nu_i(x)+(|\alpha|+\delta)\cdot\nu_i(x-x')\\ &\le \delta\cdot(\nu_i(x)+|\alpha|+\delta)\end{aligned}$$

Thus, to see the joint continuity, take δ > 0 small enough so that

$$\delta\cdot(\delta+\nu_i(x)+|\alpha|) < \varepsilon$$

Taking limited crossing points introduces no further trouble, taking the comparing limited convergences of the setsBδ and Ui,δ, Bδ and Ui,δ, completing the exhibit that isolating groups of seminorms give a structure of topological vectorspace.

Last, watch that limited crossing points of the sets Ui,ε are convex. Since convergences of convex sets are convex, it gets the job done to watch that the sets Ui,ε themselves are convex, which pursues from the homogeneity and the triangle disparity: with 0 ≤ t ≤ 1 andx,y ∈ Ui,ε,

$$\nu_i(tx+(1-t)y) \le \nu_i(tx)+\nu_i((1-t)y) = t\nu_i(x)+(1-t)\nu_i(y) \le t\varepsilon+(1-t)\varepsilon = \varepsilon$$

Thus, the set U i,ε is convex.

Tensor products of Hilbert spaces

The mathematical tensor product of two Hilbert spaces An and B has a characteristic positive clear sesquilinear structure (scalar product) actuated by the sesquilinear types of An and B. So specifically it has a characteristic positive unequivocal quadratic structure, and the relating fruition is a Hilbert space A ⊗ B, called the (Hilbert space) tensor product of An and B.

On the off chance that the vectors ai and bj go through orthonormal bases of An and B, at that point the vectors ai⊗bj structure an orthonormal premise of A ⊗ B.

Cross norms and tensor products of Banach spaces

We will utilize the documentation from (Ryan 2002) in this area. The conspicuous method to characterize the tensor product of two Banach spaces An and B is to duplicate the strategy for Hilbert spaces: characterize a standard on the mathematical tensor product, at that point take the fulfillment in this standard. The issue is that there is more than one common approach to characterize a standard on the tensor product. In the event that An and B are Banach spaces the arithmetical tensor product of An and B implies the tensor product of An and B as vector spaces and is indicated by A ⊗ B The logarithmic tensor product A ⊗ B comprises of every single limited aggregate

$$x = \sum_{i=1}^{n} a_i \otimes b_i$$

Topological Tensor Products

Let k → A1 and k → A2 be morphisms of differentiable algebras. By and large, A1 ⊗k A2 may not be a differentiable polynomial math (the tensor topology of A1 ⊗k A2 may not be finished). Give us a chance to mean by A1⊗ kA2 the culmination of A1⊗kA2. We will demonstrate that A1_ ⊗ kA2 is a differentiable variable based math and that it has the general property of a coproduct: Homk-alg(A1⊗kA2,B) = Homk-alg(A1,B) × Homk-alg(A2,B) for any morphism k → B of differentiable algebras. This outcome will be the fundamental element for the development of fibred products of differentiable spaces.

Locally Convex Modules

Give us a chance to review that a locally m-convex polynomial math is characterized to be a R-variable based math (commutative with solidarity) A supplied with a topology characterized by a family {qi} of submultiplicative seminorms:

$$q_i(ab) \leq q_i(a) q_i(b)$$

On the off chance that I is a perfect of a locally convex m-variable based math An, at that point An/I is a locally m convex polynomial math with the remainder topology: If {qi} is a major arrangement of submultiplicative seminorms of An, at that point the topology of An/I is characterized by the submultiplicative seminorms qi([a]) = infb∈I qi(a + b).

The sanctioned projection π : A → An/I is an open guide. The conclusion I of a perfect I is again a perfect of A.

Morphisms of locally *m*-convex algebras are characterized to be nonstop morphisms of R-algebras. Locally m-convex algebras, with nonstop morphisms of algebras, characterize a classification. The arrangement of all morphisms of locally m convex algebras A → B is indicated by Homm-alg(A,B). We state that a locally m-convex polynomial math is finished when so it is as a locally convex space (consequently it is isolated by definition). The finish An of a locally m-convex variable based math A will be a locally m-convex polynomial math, and it has a general property: Any morphism of locally m-convex algebras A → C, where C is finished, factors in a one of a kind route through the consummation:

$$\mathrm{Hom}_{m\text{-alg}}(\widehat{A}, C) = \mathrm{Hom}_{m\text{-alg}}(A, C)$$

Give us a chance to review that a locally m-convex polynomial math is said to be a Fr'echet variable based math in the event that it is metrizable and complete. In the event that I is a shut perfect of a Fr'echet polynomial math An, at that point An/I is a Fr'echet variable based math. Review that any differentiable variable based math, with the authoritative topology, is a Fr'echet polynomial math

Locally convex *A*-module

Let *A* be a locally *m*-convex algebra.

A **locally convex *A*-module** is characterized to be any A-module M invested with a locally convex topology to such an extent that the guide A ×M → M, (a,m) _→ am, is persistent.

On the off chance that N is a submodule of a locally convex A-module M, at that point the remainder topology characterizes on M/N a structure of locally convex A-module, in light of the fact that the accompanying square

$$\begin{array}{ccc} A \times M & \xrightarrow{\cdot} & M \\ \downarrow & & \downarrow \\ A \times (M/N) & \xrightarrow{\cdot} & M/N \end{array}$$

is commutative and A ×M → A × (M/N) is an open map. A comparable contention shows that M/IM is a locally convex (An/I)- module for any perfect I of A.

Morphisms of locally convex *A*-modules are characterized to be constant morphisms of A-modules. Locally convex A-modules, with constant morphisms of A-modules, characterize a class. The A-module of all morphisms of locally convex A-modules M → N is indicated by HomA(M,N).

A locally convex A-module is said to be finished when so it is as a locally convex vector space. The finishing _M of a locally convex A-module M is a finished locally convex _ A-module (thus a total locally convex A-module).

For any total locally convex _ A-module N, we have:

$$\mathrm{Hom}_{\widehat{A}}(\widehat{M}, N) = \mathrm{Hom}_A(\widehat{M}, N) = \mathrm{Hom}_A(M, N)$$

A locally convex *A*-module is said to be a **Fr´echet *A*-module** when so it is as a locally convex vector space. For example, if *V* is an affine smooth manifold, then the *C*∞(*V*)-module *T qp* (*V*) of all *C*∞-differentiable tensor fields of type (*p, q*) on *V*, with the topology of the uniform convergence on compact sets of the components and their derivatives, is a Fr´echet module.

Note that if *N* is a closed submodule of a Fr´echet *A*-module *M*, then *N* and *M/N* also are Fr´echet *A*-modules.

Definition. A sequence of morphisms of locally convex *A*-modules

$$M_1 \xrightarrow{j} M \xrightarrow{p} M_2 \longmapsto 0$$

is said to be a cokernel if p is a surjective open morphism and Im j is a thick subspace of Ker p.

From a thorough categorial perspective, the past definition gives the right idea of cokernel when the class of isolated locally convex A-modules is considered.

Problem of Topologies

One of the open issues in the hypothesis of Topological Tensor Products is to describe classes of locally convex spaces (1. c. s.) E and F, for which each limited subset of the finished projective XX tensor product, E⊗F, is contained in the bipolar of some set A⊗B9 where An and B are limited sets in E and F separately (Problem of Topologies) . For example it isn't known whether the Problem of Topologies has a positive answer when E and F are general Frechet spaces. Yet, on the off chance that one of the Frechet spaces is atomic, at that point it does [5].

It is the reason for this note to examine the Problem of Topologies for classes of 1. c. s. that emerge in the hypothesis of Distributions.

Before expressing our principle result, we make a few comments about the documentation. In all that pursues $\phi \equiv \bigoplus_{i=1}^{\infty} C$ will be equipped with its largest locally convex topology and $\omega \equiv \prod_{i=1}^{\infty} C$ with its product topology. An *LF*-space will be a strict inductive limit of a sequence of Frechet spaces.

Theorem. The Problem of Topologies for E⊗F has a negative arrangement assuming, either

E and F are solid duals of LF-spaces, where one of these LF spaces contains a non-normable Frechet subs pace, the other one isn't a Frechet space and both of them is atomic, or

E is a Frechet space that doesn't have a consistent standard and F a L c. s. that contains <j) as a supplemented subspace.

Three Lemmas will go before the evidence of the Theorem.

Lemma 1. Give E a chance to be a L c. s. that has a non-normable Frechet subspace and Fa L c. s. containing $ as a supplemented subspace. At that point XX — E⊗F and the finished inductive tensor product, E⊗F, have distinctive duals.

Proof

First we should accept that E is a non-normable Frechet space. As E is non-normable and metrizable, there exists a group of consistent straight practical on E, with the end goal that for no arrangement of carefully positive numbers is equicontinuous ([5], Proposition 1.7. (b) Let ∅k be a nonstop direct useful on ∅ whose portion is the place Dk(k)={0] and Dk(k =C on the off chance that n≠L, Then is an independently consistent bilinear structure on E X 0 which isn't mutually persistent. As all tensor product topologies regard supplemented subspaces, we get that (E⊗F)' = E⊗F)'.

A Hahn-Banach augmentation contention applied to the grouping gives the evidence in the general case.

Lemma 2, *Every LF-space that is not a Frechet space, has* ϕ *as a complemented subspace.*

Proof.Let *{Ej}* be a defining sequence of Frechet subspaces for *E.* There is a sequence $\{x_j\}_{j\geq 1}$ in *E* such that $x_j \in E_j$ and $x_{j+1} \notin E_j$ for all j$\geq$1. If *FJ* is the smallest subspace containing $\{x_i\}_{1\leq i\leq j}$, an inductive argument shows that there are topological complements *Gj* for *FJ* in *Ej* such that *Gj+i^Gj* for allj$\geq$l. By construction $G = \bigcup_{j=1}^{\infty} G_j$ is a subspace of countable codimension of the barrelled space *E* and therefore by the Saxon-Levin- Valdivia Theorem, *G* is barrelled ([6]. Since G is barrelled and is a union of a strictlyincreasing sequence of closed subspaces, it has the strict inductivelimit topology ([6], Definition 13-3-14 and Theorem 13-3-15). SoG is complete and therefore closed. As *E* is barrelled and G a closedsubspace of countable codimension, *F* = \J *Fh* with its largest locallyconvex topology, is a complement of G ([6], But*F* with its largest convex topology is isomorphic to <*f*>(cf. [7],.

Lemma 3*Let E and F be LF-spaces, one of them nuclear. Then E*$\otimes$F *is an LF-space and its strong dual is isomorphic to*

Proof.The principal attestation pursues from the way that the inductive tensor product topology regards inductive cutoff points [8],. Nuclearity ensures that as far as possible is exacting cf. [1].

As E⊗F and E⊗F prompt a similar topology on the Frechet subspaces of E⊗F, and each limited subset of E⊗F is contained in one of these subspaces, it pursues from the Hahn-Banach hypothesis that E⊗F is emphatically thick in E⊗F By the atomic hypothesis and the positive arrangement of the issue of Topologies for E⊗F ([10], E⊗F is firmly thick in E⊗F and thusly likewise in (F(X)F) '. Since the solid double of an atomic LF-space is atomic ([11], Proposition 21.5.1 and Corollary 21.5.5) and (E(J!)F)'B is finished (E(g)F is bornological) , it will be sufficient to show that the solid topology on (F(X)F) ' initiates the injective topology e on its thick subspace E'®Fl '. At the point when An and B differ over all conceivable

totally convex shut limited sets in E and F, separately, the seminorms

$$= (P_A \otimes_\varepsilon q_B) (\sum_{l=1}^{k} \phi_l \otimes \psi_l), \ \phi_l \in E', \ \psi_l \in F' \quad (1 \leqq l \leqq k)$$

where $P_A(\phi) \equiv \sup_{x \in A} |\phi(x)|$ and $q_B(\psi) \equiv \sup_{y \in B} |\psi(y)|$.

Proof of Theorem.

(I) By Lemmas 1 and 2 there is a nonstop seminorm p on E⊗F whose limitation to E⊗nF E⊗F furnished with the projective topology) isn't consistent. The polar BQ P of the unit ball Bp of this seminorm is a limited set in (E⊗F)'ft = E'B⊗F'fr with the end goal that for no completely convex shut limited sets An and B in Eβ and Fβ, separately,

Essentially this incorporation and the barrelledness of E and F would suggest, as in the verification of Lemma 3, that the confinement of β to E⊗F would be ceaseless.

(II) By Lemma 3 if Eø = and Fω= we have as and By part (I), this demonstrates part (ii) when E=ω. The remainder of the verification pursues from the way that each Frechet space without a ceaseless standard has co as a supplemented subspace ([12],

CONCLUSION

Here we conclude that here are usually many different ways to construct a topological tensor product of two topological vector spaces. We focused on Locally Convex Modules in topological tensor products in which covex A module is highlighted. Also we discusses Problem of opologies for E⊗F in E and F are strong duals of *LF*-spaces, and E is a Frechet space that does not have a continuous norm and F a L c. s.

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