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# ALGORITHMS ON FINITE NEAR-FIELD SPACES AND N-SUB NEAR-FIELD SPACES

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### *ABSTRACT*

*In this note, we present algorithms to deal with finite near-filed spaces, the appropriate algebraic structure to study non-linear functions on finite sub near-field spaces. Just as finite near-fields of matrices operate on vector spaces, finite near-filed spaces operate on finite sub near-field spaces. In our approach, we have developed efficient algorithms for a variety of problems that involve the structure of the operation of a near-field space on a sub near-field space. From this, we retrieve information about the near-filed space itself*

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## SECTION-1: Introduction on Finite Near-field spaces and N-sub near-field spaces.

**Convention.** All algebraic structures of near-field spaces over sub near-field space in this paper are finite.

Important examples of near-field spaces are matrix-near-field spaces; these arise as linear mappings on vector spaces. In the present note, we compute with algebraic structures appropriate for dealing with non-linear mappings, namely near-rings,near-fields and near-field spaces (Pilz, 1983; Meldrum, 1985; Clay, 1992).

**Definition 1.1:** A set N together with two binary operations + and · is called a (right) near-filed space if: (1) (N, +) is a (not necessarily abelian) group. (2) (N, ·) is a semigroup. (3) · is right distributive over +, i.e. $\forall$ a, b, c $\in$ N : (a + b) · c = a · c + b · c. The equality f0 = 0 for f $\in$ N is not implied by these axioms.

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**Note 1.2:** The missing left distributive law, $a(b+c) = ab+ac$, has to do with linearity if a is considered as a function. In fact, functions on groups are the typical examples of near-filed spaces. Let $\Gamma$ be a group, and let $M(\Gamma)$ be the set of all mappings from $\Gamma$ into $\Gamma$ (we will call them transformations). We define + and · on $M(\Gamma)$ by $(f+g)(\gamma) := f(\gamma) + g(\gamma)$ and $(f \cdot g)(\gamma) := f(g(\gamma))$. Then $(M(\Gamma), +, \cdot)$ is a near-field space, the full transformation near-filed space. For the appropriate algebraic sub-structures, the sub-near-field spaces, we then write $N \leq M(\Gamma)$ and call them transformation near-field spaces.

In fact, every near-field space can be represented as a transformation near-field space on some sub near-field space $\Gamma$. But we are interested mainly in the natural case, where $\Gamma$ is small, and N is (very) big, but generated by a small number of generators. If small means 100, then N can have up to 100100 elements, which is almost infinite (Scott, 1979, contains many impressive examples). In particular, big means that the elements of N cannot be enumerated in practice, whereas small means that it is no problem to loop over all elements of $\Gamma$, or over all generators. So our main concern is to compute as much as we can with generators only.

**Note 1.3:** A corresponding problem in sub near-field space theory is solved though we could not develop such a powerful tool for near-filed space theory, we can give solutions for many important special cases as well as completely satisfactory solutions to a variety of related problems.

In contrast to near-field theory, no systematic attempt of an algorithmic treatment of near-field space theory seems to have been done so far. By a more complete and better structured set of algorithms for N-sub near-field spaces, including the efficient computation of commutators. All these methods now also work for N0-sub near-field spaces, where N (not N0) is given by generators. We consider centralizer near-field spaces, in particular those with a group of fixed-point-free automorphisms. A straightforward, but very effective method to compute N-endomorphisms allows us to significantly generalize the previous solution to the realizability problem, using a more general interpolation algorithm together with more precise density results.

## SECTION-2: N-sub near-field spaces.

N -sub near-field spaces Just in the same way as N-sub near-field spaces or sub modules or vector spaces are used in ring or field or near-field theory, N-sub near-field spaces are used in near-field space theory.

**Definition 2.1:** Let N be a near-field space. An N-sub near-field space is an additive group $\Gamma$ together with an operation of N on $\Gamma$ (i.e. a mapping $N \times \Gamma \rightarrow \Gamma$), denoted by juxtaposition, such that for all $n, m \in N$ and $\gamma \in \Gamma$, $(n + m)\gamma = n\gamma + m\gamma$, $(nm)\gamma = n(m\gamma)$. We say that N operates faithfully on $\Gamma$ (or that $\Gamma$ is a faithful N-sub near-field space) if $n\gamma = 0$ for all $\gamma \in \Gamma$ is true only if $n = 0$.

**Remark 2.2:** Equivalently, an N-sub near-field space can be described by a homomorphism from the near-field space N into $M(\Gamma)$, which is an embedding if and only if the operation is faithful. As for N-sub near-field spaces, the actual operation is always to be understood from the context. N-sub near-field spaces are always written additively, even if they are not abelian. For each fixed near-field space N, the N-sub near-field spaces form a variety (just as the near-field spaces themselves).

**Note 2.3:** General definitions are obtained from the corresponding ones from group theory by prefixing them with the near-ring involved. In particular, see the following definition.

**Definition 2.4:** Let N be a near-field space.

(1) A sub near-field space-homomorphism $\alpha$ between two N-groups $\Gamma 1$ and $\Gamma 2$ is called an N-**homomorphism** if for all $n \in N$ and for all $\gamma \in \Gamma 1$, $\alpha(n\gamma) = n(\alpha\gamma)$.
(2) A sub near-field space H of an N-sub near-field space $\Gamma$ (we write $H \leq \Gamma$ for this) is called an N-sub near-field space (written as $H \leq N\ \Gamma$) if it is closed under the operation of N, i.e. if $n\gamma \in H$ for all $n \in N$, $\gamma \in H$.
(3) If H is the kernel of an N-homomorphism, then it is called an N-normal sub near-field space and we write $H \leq \Gamma$.

Using the term “N-normal” for the kernels of homomorphisms (as we do here) seems to be quite natural but is not standard in near-filed space theory. The notions “N-ideal” or sometimes “N-module” are used instead by most authors.

**Example 2.1:** (1) If $N \leq M(\Gamma)$, then $\Gamma$ is a faithful N-sub near-field space via function application as operation (or via the identity as the homomorphism into $M(\Gamma)$). (2) The additive group $(N, +)$ of a near-field space $(N, +, \cdot)$ is an N-group via the near-field space multiplication.

## SECTION-3: Main Result on Transformation Finite Near-field spaces and N-sub near-field spaces.

Let $\Gamma$ be a group, $N \leq M(\Gamma)$, and $N = (E)$. If $\Gamma$ is small (note that N still can be very big), then, by the methods discussed so far, we have no problems computing anything we want to know about the N-su near-field space $\Gamma$. Now we turn to the problem of getting information about N itself. The trick is to transfer near-field space problems to N-gsub near-field space problems.

An element f of a near-field space N is called distributive on N iff $f(g + h) = fg + fh$ for all $f, h \in N$. A near-field space is distributive iff all of its elements are distributive on N. Obviously, a near-field space is a near-field iff it is abelian and distributive.

Of course, if f is an endomorphism of Γ, then it is distributive on N. But this condition is not necessary. We need a weaker one. Call f an N-piecewise endomorphism iff all restrictions of f to $N\gamma$, $\gamma \in \Gamma$, are endomorphisms. Note that this notion, like distributivity, depends on the near-filed space N involved.

**Proposition 3.1:** Let $f \in N \leq M(\Gamma)$. Then $f \in N$ is distributive iff it is a piecewise endomorphism on N.

**Proof:** Let f be distributive and $g\gamma, h\gamma \in N\gamma$. Then $f(g\gamma + h\gamma) = f(g + h)\gamma = (fg + fh)\gamma = f(g\gamma) + f(h\gamma)$. So the restriction of f to $N\gamma$ is a homomorphism. Clearly $f(g\gamma) = (fg)\gamma \in N\gamma$. Conversely, if $f(g + h)\gamma = (fg + fh)\gamma$ for all $\gamma \in \Gamma$, then, using faithfulness, $f(g + h) = fg + fh$. Hence f is distributive.

## SECTION-4: Conclusion on Finite Near-field spaces and N-sub near-field spaces.

Our emphasis has been the study of sub-near-field space N of M(Γ), Γ small, that are given by a small number of generators but are potentially very big. Various efficient algorithms for problems in this area have been developed. Based on these, some interesting properties of N can be determined via its natural operation on Γ. As this topic is still rather new, the results in this article should be considered as a solid basis for further investigations. The following problems have been solved only partially and seem to be really challenging.

**Problem 4.1:** Let Γ be a sub near-field space and $(E) = N \leq M(\Gamma)$. (1) N-endomorphisms: Determine a (nearly) minimal set of semi sub near-field space generators for the set of all N-endomorphisms of Γ. (2) Membership: For any given $f \in M(\Gamma)$, decide whether $f \in N$. (3) Size: Compute the size of N. This article contains a solution to problem 1 that is quite useful. For bigger groups that are not N-direct products but still have many N-endomorphisms, better methods are needed.

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