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PCEP Extensions for Segment Routing leveraging the IPv6 data plane
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Abstract

The Source Packet Routing in Networking (SPRING) architecture describes how Segment Routing (SR) can be used to steer packets through an IPv6 or MPLS network using the source routing paradigm. Segment Routing (SR) enables any head-end node to select any path without relying on a hop-by-hop signaling technique (e.g., LDP or RSVP-TE).

It depends only on "segments" that are advertised by Link- State Interior Gateway Protocols (IGPs). A Segment Routed Path can be derived from a variety of mechanisms, including an IGP Shortest Path Tree (SPT), explicit configuration, or a Path Computation Element (PCE).

Since, Segment Routing can be applied to both MPLS and IPv6 forwarding plane, a PCE should be able to compute SR-Path for both MPLS and IPv6 forwarding plane. This draft describes the extensions required for Segment Routing support for IPv6 data plane in PCEP.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

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1. Introduction

As per [I-D.ietf-spring-segment-routing], with Segment Routing (SR), a node steers a packet through an ordered list of instructions, called segments. A segment can represent any instruction, topological or service-based. A segment can have a semantic local to an SR node or global within an SR domain. SR allows to enforce a flow through any path and service chain while maintaining per-flow state only at the ingress node of the SR domain. Segments can be derived from different components: IGP, BGP, Services, Contexts, Locators, etc. The list of segment forming the path is called the Segment List and is encoded in the packet header. Segment Routing can be applied to the IPv6 architecture with the Segment Routing Header (SRH) [I-D.ietf-6man-segment-routing-header]. A segment is encoded as an IPv6 address. An ordered list of segments is encoded as an ordered list of IPv6 addresses in the routing header. The active segment is indicated by the Destination Address of the packet. Upon completion of a segment, a pointer in the new routing header is incremented and indicates the next segment.

Segment Routing use cases are described in [RFC7855] and [I-D.ietf-spring-ipv6-use-cases]. Segment Routing protocol extensions are defined in [I-D.ietf-isis-segment-routing-extensions], and [I-D.ietf-ospf-ospfv3-segment-routing-extensions].

As per [I-D.ietf-6man-segment-routing-header], an SRv6 Segment is a 128-bit value. "SRv6 SID" or simply "SID" are often used as a shorter reference for "SRv6 Segment". Further details are in an illustration provided in [I-D.filsfils-spring-srv6-network-programming].

The SR architecture can be applied to the MPLS forwarding plane without any change, in which case an SR path corresponds to an MPLS Label Switching Path (LSP). The SR is applied to IPV6 forwarding plane using SRH. A SR path can be derived from an IGP Shortest Path Tree (SPT), but SR-TE paths may not follow IGP SPT. Such paths may be chosen by a suitable network planning tool, or a PCE and provisioned on the ingress node.

[RFC5440] describes Path Computation Element Protocol (PCEP) for communication between a Path Computation Client (PCC) and a Path

Computation Element (PCE) or between a pair of PCEs. A PCE or a PCC operating as a PCE (in hierarchical PCE environment) computes paths for MPLS Traffic Engineering LSPs (MPLS-TE LSPs) based on various constraints and optimization criteria. [RFC8231] specifies extensions to PCEP that allow a stateful PCE to compute and recommend network paths in compliance with [RFC4657] and defines objects and TLVs for MPLS-TE LSPs. Stateful PCEP extensions provide synchronization of LSP state between a PCC and a PCE or between a pair of PCEs, delegation of LSP control, reporting of LSP state from a PCC to a PCE, controlling the setup and path routing of an LSP from a PCE to a PCC. Stateful PCEP extensions are intended for an operational model in which LSPs are configured on the PCC, and control over them is delegated to the PCE.

A mechanism to dynamically initiate LSPs on a PCC based on the requests from a stateful PCE or a controller using stateful PCE is specified in [RFC8281]. As per [I-D.ietf-pce-segment-routing], it is possible to use a stateful PCE for computing one or more SR-TE paths taking into account various constraints and objective functions. Once a path is chosen, the stateful PCE can initiate an SR-TE path on a PCC using PCEP extensions specified in [RFC8281] using the SR specific PCEP extensions specified in [I-D.ietf-pce-segment-routing]. [I-D.ietf-pce-segment-routing] specifies PCEP extensions for supporting a SR-TE LSP for MPLS data plane. This document extends [I-D.ietf-pce-segment-routing] to support SR for IPv6 data plane. Additionally, using procedures described in this document, a PCC can request an SRv6 path from either stateful or a stateless PCE. This specification relies on the PATH-SETUP-TYPE TLV and procedures specified in [I-D.ietf-pce-lsp-setup-type].

2. Terminology

This document uses the following terms defined in [RFC5440]: PCC, PCE, PCEP Peer.

This document uses the following terms defined in [RFC8051]: Stateful PCE, Delegation.

The message formats in this document are specified using Routing Backus-Naur Format (RBNF) encoding as specified in [RFC5511].

PCC: Path Computation Client.

PCE: Path Computation Element.

PCEP: Path Computation Element Protocol.

SR: Segment Routing.

SID: Segment Identifier.

SRv6: Segment Routing for IPv6 forwarding plane.

SRH: IPv6 Segment Routing Header.

SR Path: IPv6 Segment (List of IPv6 SID representing a path in IPv6 SR domain)

3. Overview of PCEP Operation in SRv6 Networks

Basic operations for PCEP speakers is as per [I-D.ietf-pce-segment-routing]. SRv6 Paths computed by a PCE can be represented as an ordered list of SRv6 segments of 128-bit value. "SRv6 SID" or simply "SID" are often used as a shorter reference for "SRv6 Segment" in this document.

[I-D.ietf-pce-segment-routing] defined a new ERO subobject denoted by "SR-ERO subobject" capable of carrying a SID as well as the identity of the node/adjacency represented by the SID. SR-capable PCEP speakers should be able to generate and/or process such ERO subobject. An ERO containing SR-ERO subobjects can be included in the PCEP Path Computation Reply (PCRep) message defined in [RFC5440], the PCEP LSP Initiate Request message (PCInitiate) defined in [RFC8281], as well as in the PCEP LSP Update Request (PCUpd) and PCEP LSP State Report (PCRpt) messages defined in defined in [RFC8231].

This document extends the "SR-ERO subobject" defined in [I-D.ietf-pce-segment-routing] to carry IPv6 SID(s) (IPv6 Addresses). SRv6-capable PCEP speakers should be able to generate and/or process this.

When a PCEP session between a PCC and a PCE is established, both PCEP speakers exchange their capabilities to indicate their ability to support SRv6 specific functionality.

In summary, this document defines new path setup type carried in the PATH-SETUP-TYPE TLV for SRv6 path.

In summary, this document:

- o Defines a new PCEP capability for SRv6
- o Update the SR-ERO and SR-RRO sub-object for SRv6
- o Defines a new path setup type carried in the PATH-SETUP-TYPE TLV for SR-TE LSP.

3.1. Operation Overview

In SR networks, an ingress node of an SR path appends all outgoing packets with an SR header consisting of a list of SIDs (IPv6 Prefix in case of SRv6). The header has all necessary information to guide the packets from the ingress node to the egress node of the path, and hence there is no need for any signaling protocol.

For IPv6 in control plane with MPLS data-plane, mechanism remains same as [I-D.ietf-pce-segment-routing]

This document describes extensions to SR path for IPv6 data plane. SRv6 Path (i.e. ERO) consists of an ordered set of SIDs(see details in Figure 2).

A PCC or PCE indicates its ability to support SRv6 during the PCEP session Initialization Phase via a new SRv6-PCE-CAPABILITY sub-TLV (see details in Section 3.3.1.1).

3.2. SRv6-Specific PCEP Message Extensions

As defined in [RFC5440], a PCEP message consists of a common header followed by a variable length body made up of mandatory and/or optional objects. This document does not require any changes in the format of PCReq and PCRep messages specified in [RFC5440], PCInitiate message specified in [RFC8281], and PCRpt and PCUpd messages specified in [RFC8231]. However, PCEP messages pertaining to SRv6 MUST include PATH-SETUP-TYPE TLV in the RP or SRP object to clearly identify that SRv6 is intended. In other words, a PCEP speaker MUST NOT infer whether or not a PCEP message pertains to SRv6 from any other object or TLV.

3.3. Object Formats

3.3.1. The OPEN Object

3.3.1.1. The SRv6 PCE Capability sub-TLV

This document defines a new Path Setup Type (PST) [I-D.ietf-pce-lsp-setup-type] for SRv6, as follows:

o PST = TBD2: Path is setup using SRv6.

A PCEP speaker SHOULD indicate its support of the function described in this document by sending a PATH-SETUP-TYPE-CAPABILITY TLV in the OPEN object with this new PST included in the PST list.

This document also defines the SRv6-PCE-CAPABILITY sub-TLV. PCEP speakers use this sub-TLV to exchange information about their SRv6 capability. If a PCEP speaker includes PST=TBD2 in the PST List of the PATH-SETUP-TYPE-CAPABILITY TLV then it MUST also include the SRv6-PCE- CAPABILITY sub-TLV inside the PATH-SETUP-TYPE-CAPABILITY TLV.

The format of the SRv6-PCE-CAPABILITY sub-TLV is shown in the following figure:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Type=TBD1          |            Length=4           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      max-SL   |  Reserved     |             Flags           |L|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 1: SRv6-PCE-CAPABILITY sub-TLV format

The code point for the TLV type (TBD1) is to be defined by IANA. The TLV length is 4 octets.

The 4-octet value comprise of -

max-SL: 1 octet, this field specifies the maximum value of the "Segments Left (SL)" in the SRH [I-D.ietf-6man-segment-routing-header].

Reserved: 1 octet, this field MUST be set to 0 on transmission, and ignored on receipt.

Flags: 2 octet, one flag is currently defined in this document.

L bit: A PCC sets this bit to 1 to indicate that it does not impose any limit on SL.

3.3.1.2. Exchanging the SRv6 Capability

A PCC indicates that it is capable of supporting the head-end functions for SRv6 by including the SRv6-PCE-CAPABILITY sub-TLV in the Open message that it sends to a PCE. A PCE indicates that it is capable of computing SRv6 paths by including the SRv6-PCE-CAPABILITY sub-TLV in the Open message that it sends to a PCC.

If a PCEP speaker receives a PATH-SETUP-TYPE-CAPABILITY TLV with a PST list containing PST=TBD2, but the SRv6-PCE-CAPABILITY sub-TLV is absent, then the PCEP speaker MUST send a PCErr message with Error-Type 10 (Reception of an invalid object) and Error-Value TBD5 (to be assigned by IANA) (Missing PCE-SRv6-CAPABILITY sub-TLV) and MUST then close the PCEP session. If a PCEP speaker receives a PATH-SETUP-TYPE-CAPABILITY TLV with a SRv6-PCE-CAPABILITY sub-TLV, but the PST list does not contain PST=TBD2, then the PCEP speaker MUST ignore the SRv6-PCE-CAPABILITY sub-TLV.

The number of SIDs that can be imposed on a packet depends on the PCC's IPv6 data plane's capability. If a PCC sets the L flag to 1 then the max-ML is not used and MUST be set to zero. If a PCE receives an SRv6-PCE-CAPABILITY sub-TLV with the L flag set to 1 then it MUST ignore the max-SL field and MUST assume that the sender can impose a SL of any depth. If a PCC sets the L flag to zero, then it sets the max-SL field to the maximum number of SIDs that it can impose on a packet. If a PCE receives an SRv6-PCE-CAPABILITY sub-TLV with the L flag and max-SL both set to zero then it MUST assume that the PCC is not capable of imposing a SL of any length and hence is not SRv6 capable, unless it learns a non-zero max-SL for the PCC through some other means.

Once an SRv6-capable PCEP session is established with a non-zero max-SL value, the corresponding PCE MUST NOT send SRv6 paths with a number of SIDs exceeding that max-SL value. If a PCC needs to modify the max-SL value, it MUST close the PCEP session and re-establish it with the new max-SL value. If a PCEP session is established with a non-zero max-SL value, and the PCC receives an SRv6 path containing more SIDs than specified in the max-SL value, the PCC MUST send a PCErr message with Error-Type 10 (Reception of an invalid object) and Error-Value 3 (Unsupported number of Segment ERO subobjects). If a PCEP session is established with an max-SL value of zero, then the PCC MAY specify an max-SL for each path computation request that it sends to the PCE, by including a "maximum SID depth" metric object on the request similar to [I-D.ietf-pce-segment-routing].

The L flag and Max-SL value inside the SRv6-PCE-CAPABILITY sub-TLV are meaningful only in the Open message sent from a PCC to a PCE. As such, a PCE MUST set the L flag and Max-SL value to zero in an outbound message to a PCC. Similarly, a PCC MUST ignore any max-SL value received from a PCE. If a PCE receives multiple SRv6-PCE-CAPABILITY sub-TLVs in an Open message, it processes only the first sub-TLV received.

3.3.2. The RP/SRP Object

In order to indicate the SRv6 path, RP or SRP object MUST include the PATH-SETUP-TYPE TLV specified in [I-D.ietf-pce-lsp-setup-type]. This document defines a new Path Setup Type (PST=TBD2) for SRv6.

3.3.3. ERO Object

In order to support SRv6, the SR-ERO subobject is used [I-D.ietf-pce-segment-routing]. All other processing rules remains the same.

3.3.3.1. SR-ERO Subobject

For supporting SRv6, a new SID Type (ST) is defined, the format of SR-ERO sub object remains the same as defined in [I-D.ietf-pce-segment-routing].

When the SID Type (ST) indicates SRv6, then the SR-ERO subobject represent a SRv6 segment and include a field SRv6I (SRv6 Identifier) in place of NAI (Node or Adjacency Identifier) defined in [I-D.ietf-pce-segment-routing]. The 32 bit SID MUST be set to zero on transit and ignored on receipt. The format of SR-ERO subobject is reproduced with the SRv6I field as shown below:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|L|    Type     |     Length    |  ST   |     Flags     |F|S|C|M|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              SID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                      SRv6I (variable)                       //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: SR-ERO Subobject Format

The description of all the flags and fields is as per [I-D.ietf-pce-segment-routing].

For SRv6 segments, a new ST (SID Type) is assigned by IANA as TBD3.

For SRv6 segments (when ST is TBD3), M and C flag MUST NOT be set. The S flag MUST be set and SID field MUST be set to 0. The F bit MUST NOT be set. The Length is 28.

The SRv6I format is as shown below:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                       SRv6 Identifier                         |
|                          (128-bit)                            |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| SRv6ST|         Flags             |       Function Code       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                         NAI (variable)                      //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 3: SR-ERO Subobject's SRv6I Format

SRv6 Identifier is the 128 bit IPv6 addresses representing SRv6 segment.

SRv6ST is the SRv6 SID Type which indicates the interpretation for NAI (Node or Adjacency Identifier) as per [I-D.ietf-pce-segment-routing].

Flags is the 12 bit field, no flag bits are currently defined in this document.

Function Code is is the 16 bit field representing supported functions. associated with SRv6 SIDs. [Editor's Note - The authors needs to finalize if this functionality be removed for now, with a possibility for addition in another extention as the [I-D.filsfils-spring-srv6-network-programming] progressses]. Following function codes are currently defined -

0: Reserved

1: End Function

2: End.DX6 Function

3: End.DT6 Function

4: End.X Function

NAI field [I-D.ietf-pce-segment-routing] contains the NAI associated with the SRv6 Identifier. Depending on the value of SRv6ST, the NAI can have different formats.

When SRv6ST value is 1, the NAI is as per the 'IPv6 Node ID' format defined in [I-D.ietf-pce-segment-routing], which specify an IPv6 address. This is used to identify the owner of the SRv6 Identifier.

When SRv6ST value is 2, the NAI is as per the 'IPv6 Adjacency' format defined in [I-D.ietf-pce-segment-routing], which specify a pair of IPv6 addresses. This is used to identify the IPv6 Adjacency and used with the SRv6 Adj-SID.

Note that when SRv6ST value is 0, NAI is not included and MUST be NULL.

3.3.3.2. ERO Processing

The ERO and SR-ERO subobject processing remains as per [RFC5440] and [I-D.ietf-pce-segment-routing].

The ST MUST only be TDB3, if the PST=TBD3 is set in the PCEP message and SRv6-PCE-CAPABILITY sub-TLV is exchanged with the PCEP peer. In case a PCEP speaker receives the SR-ERO subobject with ST indicating SRv6 segment, when the PST is not set to TBD3 or SRv6-PCE-CAPABILITY sub-TLV was not exchanged, it MUST send a PCErr message with Error-Type = 19 ("Invalid Operation") and Error-Value = TBD4 ("Attempted SRv6 when the capability was not advertised"). A PCEP speaker that does not recognize the ST value, it would behave as per [I-D.ietf-pce-segment-routing].

[Editor's Note - this is missing from [I-D.ietf-pce-segment-routing].]

If a PCC receives a list of SRv6 segments, and the number of SRv6 segments exceeds the max-SL that the PCC can impose on the packet (SRH), it MAY send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Unsupported number of Segment ERO subobjects") as per [I-D.ietf-pce-segment-routing].

When a PCEP speaker detects that all subobjects of ERO are not identical to SRv6, and if it does not handle such ERO, it MUST send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Non-identical ERO subobjects")as per [I-D.ietf-pce-segment-routing].

When a PCEP speaker receives an SR-ERO subobject for SRv6 segment, M, C and F flag MUST NOT be set and S flag MUST be set. Otherwise, it MUST consider the entire ERO object invalid and send a PCErr message with Error-Type = 10 ("Reception of an invalid object") and Error-Value = TBD ("Malformed object") as per [I-D.ietf-pce-segment-routing]. The PCEP speaker MAY include the malformed SR-ERO object in the PCErr message as well.

3.3.4. RRO Object

In order to support SRv6, the SR-ERO Subobject is used [I-D.ietf-pce-segment-routing]. All other processing rules remains the same.

3.3.4.1. SR-RRO Subobject

For SRv6 segments, a new ST (SID Type) is assigned by IANA as TBD3, the format of SR-ERO sub object remains the same as defined in [I-D.ietf-pce-segment-routing].

When the SID Type (ST) indicates SRv6, then the SR-RRO subobject represent a SRv6 segment and include a field SRv6I (SRv6 Identifier) in place of NAI (Node or Adjacency Identifier) defined in [I-D.ietf-pce-segment-routing]. The 32 bit SID MUST be set to zero on transit and ignored on receipt. The format of SR-RRO subobject is reproduced with the SRv6I field as shown below:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Type     |     Length    |  ST   |     Flags     |F|S|C|M|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                              SID                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
//                      SRv6I (variable)                       //
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 4: SR-RRO Subobject Format

The description of all fields and flags is as per SR-ERO subobject.

Processing rules of SR-RRO subobject are identical to those of SR-ERO subobject.

If a PCE detects that all subobjects of RRO are not identical, and if it does not handle such RRO, it MUST send a PCErr message with Error-

Type = 10 ("Reception of an invalid object") and Error-Value = 10 ("Non-identical RRO subobjects").

3.4. Security Considerations

The security considerations described in [RFC5440], [RFC8231] and [RFC8281], [I-D.ietf-pce-segment-routing], are applicable to this specification. No additional security measure is required.

3.5. IANA Considerations

This document requests IANA to include (I) bit in flags registry for SR-ERO and SR-RRO sub-objects. Other changes are defined as:

3.5.1. PCEP Objects

3.5.1.1. ERROR Objects

IANA is requested to allocate code-points in the PCEP-ERROR Object Error Types and Values registry for the following new error-values:

Error-Type	Meaning
10	Reception of an invalid object Error-value = TBD5 (Missing PCE-SRv6-CAPABILITY sub-TLV)
19	Invalid Operation Error-value = TBD4 (Attempted SRv6 when the capability was not advertised)

3.5.1.2. TLV Type Indicators

IANA is requested to make the assignment of the new code points for the existing "PCEP TLV Type Indicators" registry as follows:

Value	Meaning	Reference
TBD1	SRv6-PCE-CAPABILITY	This Document

3.5.1.3. New Path Setup Type

[I-D.ietf-pce-lsp-setup-type]defines the PATH-SETUP-TYPE TLV and requests that IANA creates a registry to manage the value of the PATH-SETUP-TYPE TLV's PST field. IANA is requested to allocate a new code point in the PCEP PATH_SETUP_TYPE TLV PST field registry, as follows:

Value	Description	Reference
TBD2	SRv6 (SRH) technique	This Document

3.6. The SID Type field

[Editor's Note - an IANA code point sub registry needs to be setup in [I-D.ietf-pce-segment-routing], so that future extensions (like this one) can define new ST types (TBD3).]

4. References

4.1. Normative References

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