This paper proposes a library mechanism for deconstructing types that parallels the language mechanism described in Structured binding P0144R2. This proposal name a type concerned by structured binding a Product Type. The interface includes getting the number of elements, access to the nth element and the type of the nth element.

The main benefits of this are cheap reflection, allow automatic serialization support, automated interfaces, etc.

In addition, some of the algorithms that work for tuple-like access types are adapted to work with Product-Types.

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### History

- R1
  - Adaptation to the adopted structured binding paper P0217R3.
  - Addition of algorithms working on Product-Types.
  - Adaptation of <tuple>, <utility> and <array> to Product-Types.

### Introduction

Defining tuple-like access tuple_size, tuple_element and get<I>/get<T> for simple classes is -- as for comparison operators (N4475) -- tedious, repetitive, slightly error-prone, and easily automated.

P0144R2/P0217R3 proposes the ability to bind all the members of some type, at a time via the new structured binding statement. This proposal names those types product types.

P0197R6 proposed the generation of the tuple-like access function for simple structs as the P0144R2 does for simple structs (case 3).

This paper proposes a library interface to access the same types covered by Structured binding P0144R2, product types. The interface includes getting the number of elements, access to the nth element and the type of the nth element. This interface doesn't use ADL.

The wording of Structured binding has been modified so that both structured binding and the possible product type access wording isn't repetitive.

### Motivation

Besides std::pair, std::tuple and std::array, aggregates in particular are good candidates to be considered as tuple-like types. However defining the tuple-like access functions is tedious, repetitive, slightly error-prone, and easily automated.

Some libraries, in particular Boost Fusion and Boost Hana provide some macros to generate the needed reflection instantiations. Once this reflection is available for a type, the
user can use the struct in algorithms working with heterogeneous sequences. Very often, when macros are used for something, it is hiding a language feature.

**P0144R2** proposes the ability to bind all the members of a tuple-like type at a time via the new structured binding statement. **P0197R0** proposes the generation of the tuple-like access function for simple structs as the **P0144R2** does for simple structs (case 3 in **P0144R2**).

The wording in **P0217R3**, allows to do structure binding for C-arrays and allow bitfields as members in case 3 (built-in). But

- bitfields cannot be managed by the current tuple-like access function `get<I>(t)` without returning a bitfields reference wrapper, so **P0197R0** doesn’t provides a tuple-like access for all the types supported by **P0217R3**.
- we are unable to find a `get<I>(arr)` overload on C-arrays using ADL.

This is unfortunately asymmetric. We want to have structure binding, pattern matching and product types access for the same types.

This means that the extended tuple-like access cannot be limited to tuple-like access.

Algorithms such as `std::tuple_cat` and `std::experimental::apply` that work well with tuple-like types, should work also for product types. There are many more of them; a lot of the homogeneous container algorithm are applicable to heterogeneous containers and functions, see [Boost Fusion](https://www.boost.org/doc/libs/1_76_0/libs/fusion/doc/index.html) and [Boost Hana](http://www.boost.org/doc/libs/1_76_0/libs/hana/doc/index.html). Some examples of such algorithms are `swap`, `lexicographical_compare`, `for_each`, `filter`, `find`, `fold`, `any_of`, `all_of`, `none_of`, `accumulate`, `count`, ...

Other algorithms that need in addition that the `ProductType` to be also `TypeConstructible` are e.g. `transform`, `replace`, `join`, `zip`, `flatten`...

### Ability to work with bitfields

To provide extended tuple-like access for all the types covered by **P0144R2** which support getting the size and the n\textsuperscript{th} element, we would need to define some kind of predefined operators `pt_size(T)` / `pt_get(N, pt)` that could use the new product type customization points. The use of operators, as opposed to pure library functions, is particularly required to support bitfield members.

The authors don’t know how to define a function interface that could manage with bitfield references. See **P0326R0** “Ability to work with bitfields only partially” for a description of the customization issues.

### Parameter packs

We shouldn’t forget parameter packs, which could be seen as being similar to product types. Parameter packs already have the `sizeof...(T)` operator. Some (see e.g. **P0311R0** and references therein) are proposing to have a way to explicitly access the n\textsuperscript{th} element of a pack (a variety of possible syntaxes have been suggested). The authors believe that the same operators should apply to parameter packs and product types.

### Proposal

Taking into consideration these points, this paper proposes a product type access library interface as well as a number of functions that can be built on top of this access functions.

### Future Product type operator proposal (Not yet)

We don’t propose yet the product type operators to get the size and the n\textsuperscript{th} element as we don’t have a good proposal for the operators’s name. We prefer to wait until we have some concrete proposal for parameter packs direct access.

The product type access could be based on two operators: one `pt_size(T)` to get the size and the other `pt_get(N, pt)` to get the N\textsuperscript{th} element of a product type instance `pt` of type `T`. The definition of these operators would be based on the wording of structured binding **P0217R3**.

The name of the operators `pt_size` and `pt_get` are of course subject to bike-shedding.

But what would be the result type of those operators? While we can consider `pt_size` as a function and we could say that it returns an `unsigned int`, `pt_get(N,pt)` wouldn’t be a function (if we want to support bitfields), and so `decltype(pt_get(N,pt))` wouldn’t be defined if the N\textsuperscript{th} element is a bitfield managed on **P0144R2** case 3. In all the other cases we can define it depending on the const-value nature of `pt`.

The following could be syntactic sugar for those operators but we don’t propose them yet. We wait to see what we do with parameter packs direct access and sum types.

- `pt_size(PT) = sizeof...(PT)`
- `pt_get(N, pt) = pt.[N]`

### Caveats

1. `pt_size(T)`, `pt_element(T)` and `pt_get(N, pt)` aren’t functions nor traits, and so they cannot be used in any algorithm expecting a function or a traits as parameter.
2. We need to find the name for those operators.

### Product type library proposal

An alternative is to define generic function `std::product_type::get<I>(pt)` and traits `std::product_type::size<PT>::value` using wording similar to that in **P0217R3**.
The interface tries to follow in someway the guidelines presented in N4381.

We have two possibilities for std::product_type::get: either it supports bitfield elements and we need a std::bitfield_ref type, or it doesn't support them.

We believe that we should provide a bitfield_ref class in the future, but this is out of the scope of this paper.

However, we can already define the functions that will work well with all the product types expect for bitfields.

```cpp
namespace std {
    namespace product_type {
        template <class PT>
        struct size;
        // Wouldn't work for bitfields
        template <size_t N, class PT>
        constexpr auto get(PT&& pt)
        template <size_t N, class PT>
        struct element;
    }
}
```

While this could be seen as a limitation, and it would be in some cases, we can already start to define a lot of algorithms.

Users could already define their own bitfield_ref class and define its customization point for bitfields members if needed when structured binding will be updated to allow bitfield customization.

Waiting for that, the user will need to wrap the bitfields in a specific structure and do bit manipulation outside independently of the product type access.

### Algorithms and function adaptation

#### std::tuple_cat

Adapt the definition of std::tuple_cat in [tuple.creation] to take care of product type

NOTE: This algorithm could be moved to a product type specific algorithms file.

#### Constructor from a product type with the same number of elements as the tuple

Similar to the constructor from pair.

This simplifies a lot the std::tuple interface (See N4387).

#### std::apply

Adapt the definition of std::apply in [xxx] to take care of product type

NOTE: This algorithm could be moved to a product type specific algorithms file.

#### std::pair

piecewise constructor

The following constructor could also be generalized to product types

```cpp
template <... Args1, ... Args2>
pair(piecewise_construct_t,
     tuple<Args1...> first_args, tuple<Args2...> second_args);
```

```cpp
template <class PT1, class PT2>
pair(piecewise_construct_t, PT1 first_args, PT2 second_args);
```

#### Constructor and assignment from a product type with two elements

Similar to the tuple constructor from pair.

This simplifies a lot the std::pair interface (See N4387).

### Design Rationale
What do we loss if we don’t add this *product type* access?

We will be unable to define algorithms working on the same kind of types supported by Structured binding [P0144R2].

While Structured binding is a good tool for the user, it is not adapted to the library authors, as we need to know the number of elements of a product type to do Structured binding.

This means that the user would continue to write generic algorithms based on the *tuple-like* access and we don’t have a *tuple-like* access for c-arrays (which could be added) and for the types covered by Structured binding case 3 [P0217R3].

Traits versus functions

Should the *product type* *size* access be a constexpr function or a trait?

We have chosen a traits to be inline with *tuple-like* access. Note that the trait defines the function call

```
auto s = product_type::size<PT>();
```

Note also that having a function to get the element type is not natural and its use is not friendly.

Locating the interface on a specific namespace

The name of *product type* interface, *size*, *get*, *element*, are quite common. Nesting them on a specific namespace makes the intent explicit.

We can also preface them with *product_type_*, but the role of namespaces was to be able to avoid this kind of prefixes.

Namespace versus struct

We can also place the interface nested on a struct. Using a namespace has the advantage is open for addition. It can also be used with using directives and using declarations.

Using a *struct* would make the interface closed to adding new nested functions, but it would be open by derivation.

What we surely need is an *explicit namespace* that is open for additions and that request explicit qualification. [N1691] "Explicit Namespaces" suggest something like that, but goes too far.

Other functions for *ProductType*

There are a lot of useful function associated to product types that make use only of the product type access traits and functions.

**apply**

```
template <class F, class ProductType>
constexpr decltype(auto) apply(F&& f, ProductType&& pt);
```

This is the equivalent of *std::apply* applicable to product types instead of tuple-like types.

```
std::apply could be defined in function of it.
```

**assign**

```
template <class PT1, class PT2>
PT1& assign(PT1& pt1, PT2&& pt2);
```

Assignment from another product type with the same number of elements and convertible elements.

This function can be used while defining the *operator=* on product types. See the wording changes for *std::tuple*, *std::pair* and *std::array*.

**for_each**

```
template <class F, class ProductType>
constexpr void for_each(F&& f, ProductType&& pt);
```

This is the equivalent of *std::for_each* applicable to product types instead of homogeneous containers or range types.

**make_from**
```cpp
template <class T, class ProductType>
constexpr `see below` make_from(ProductType&& pt);
```

This is the equivalent of `std::make_from_tuple` applicable to product types instead of tuple-like types. `std::make_from_tuple` could be defined in function of it.

This function is similar to `apply` when applied with a specific `construct<T>` function.

### swap

```cpp
template <class PT>
void swap(PT & x, PT & y) noexcept(`see below`);
```

Swap of two product types.

This function can be used while defining the `swap` on the namespace associated to the product type.

If we adopt were able to customize `swap` for concepts as in `SWAPPABLE` we could even be able to customize the swap operation for `ProductTypes`.

### to_tuple

```cpp
template <class ProductType>
constexpr `see below` to_tuple(ProductType&& pt);
```

`std::tuple` is the more generic product type. Some functions could expect a specific `std::tuple` product type.

### fold_left / fold_right / accumulate

This is the equivalent of `std::accumulate` applicable to product types instead of homogeneous containers types.

### lexicographical_compare

This is the equivalent of `std::lexicographical_compare` applicable to product types instead of homogeneous containers types.

This function can be used while defining the comparison operators on product types when the default comparisons [N4475](https://www.open-std.org/jtc1/sc22/wg21/docs/papers/2017/n4475.html) are not applicable. Note that default comparison is not applicable to all the `Product Types`, in particular the product types customized by the user.

This function requires that all the element of the product type are `OrderedComparable`.

### all_of

Checks if n-unary n-predicate `p` returns `true` for all elements in the product type.

### any_of

Checks if n-unary n-predicate `p` returns `true` for at least one elements in the product type.

### none_of

Checks if n-n-unary predicate `p` returns `true` for no elements in the product type.

### Other functions for `TypeConstructible ProductTypes`

Some algorithms need a `TypeConstructible ProductTypes` as they need to construct a new instance of a `ProductTypes`.

An alternative is to use `std::tuple` as the parameter determining the `Product Type` to construct.

We could also add a `TypeConstructible` parameter, as e.g.

```cpp
template <template <...> TC, class ...ProductTypes>
constexpr `see below` cat(ProductTypes&& ...pts);
```
Where TC is a variadic template for a ProductType as e.g. `std::tuple` or a TypeConstructor P0343R0.

cat

```cpp
template <class ...ProductTypes>
constexpr `see below` cat(ProductTypes&& ...pts);
```

This is the equivalent of `std::tuple_cat` applicable to product types instead of tuple-like types. This function requires the first Product Type to be Type Constructible.

An alternative is to use `std::tuple` when the first Product Type is not Type Constructible.

We could also have

```cpp
template <template <class ...ProductTypes> TC, class ...ProductTypes>
constexpr `see below` cat(ProductTypes&& ...pts);
```
```cpp
template <class TC, class ...ProductTypes>
constexpr `see below` cat(ProductTypes&& ...pts);
```

Where TC is a variadic template for a ProductType as e.g. `std::tuple` or a TypeConstructor [TypeConstructor].

`std::tuple_cat` could be defined in function of it one of the alternatives.

transform

```cpp
template <class F, class ProductType>
constexpr `see below` transform(FAA f, ProductType& pt);
```

This is the equivalent of `std::transform` applicable to product types instead of homogeneous containers types.

This needs in addition that ProductType is TypeConstructible (See P0338R0). Note that `std::pair`, `std::tuple` and `std::array` are TypeConstructible, but `std::pair` and `std::array` limit either in the number or in the kind of types (all the same). A c-array is not type TypeConstructible as it cannot be returned by value.

Proven Wording

The proposed changes are expressed as edits to N5131 Working Draft, Standard for Programming Language C++.

Note that the wording for the “Product types terms” section have not been adapted to the current

Add the following section

Product types terms

If E is an array type with element type T,

- the product type size of E is equal to the number of elements of E,
- the product type i\textsuperscript{th}-element of E is e[i-1].
- the product type i\textsuperscript{th}-element type of E is T.

[Note: The top-level cv-qualifiers of T are cv. — end note]

Otherwise, if the expression `std::tuple_size<E>::value` is a well-formed integral constant expression,

- the product type size of E is equal to `std::tuple_size<E>::value`.
- the product type i\textsuperscript{th}-element type of E is this type.

The unqualified-id `get` is looked up in the scope of E by class member access lookup (3.4.5), and if that finds at least one declaration, the initializer is `e.get<i - 1>()`. Otherwise, the initializer is `get<i - 1>(e)`, where get is looked up in the associated namespaces (3.4.2). In either case, `get<i - 1>` is interpreted as a template-id. [Note: Ordinary unqualified lookup (3.4.1) is not performed. — end note]

- the product type i\textsuperscript{th}-element of E is this initializer.
- the product type size of E is equal to the number of non-static data members of E.
- the product type i\textsuperscript{th}-element of E is e.mi.
- the product type i\textsuperscript{th}-element type of E is the declared type of that E::mi.

Otherwise all of E’s non-static data members shall be public direct members of E or of the same unambiguous public base class of E. E shall not have an anonymous union member. The i\textsuperscript{th} non-static data member of E in declaration order is designated by mi.

- the product type size of E is equal to the number of non-static data members of E.
- the product type i\textsuperscript{th}-element of E is e.mi.
- the product type i\textsuperscript{th}-element type of E is the declared type of that E::mi.

Otherwise the terms are undefined.
If any of the previous terms is not defined the other are not defined.

Add a new `<product_type>` file in 17.6.1.2 Headers [headers] Table 14

Add the following section in N4564

---

**Product type object**

---

### Product type synopsis

```cpp
namespace std {
    template <class PT-
        struct is_product_type;

namespace product_type {
    template <class PT-
        struct size;
        template <size_t N, class PT-
            constexpr auto get(PT & pt);
        template <size_t I, class PT-
            struct element;
    }
}
```

**Template Class product_type::size**

```cpp
template <class PT-
    struct size : integral_constant<size_t, `see below`> {};
```

**Remark:** If product type size `PT` is defined, the value of the integral constant is product type size `PT`. Otherwise the trait is undefined.

**Note:** In order to implement this trait library it would be required that the compiler provides some builtin as e.g. `__builtin_pt_size(PT)` that implements product type size `PT`.

**Template Class product_type::element**

```cpp
template <class PT-
    struct element { using type = `see below`;
};
```

**Remark:** If product type Nth-element type of PT is defined the nested alias `type` is product type Nth-element type of PT. Otherwise it is undefined.

**Note:** In order to implement this trait library it would be required that the compiler provides some builtin as e.g. `__builtin_pt_element_type(N, PT)` that implements product type Nth-element type of PT.

**Function Template product_type::get**

```cpp
template <size_t N, class PT-
    constexpr auto get(PT & pt);
```

**Requires:** `N < size<PT>()`

**Returns:** the "product type N th-element" of `pt`.

**Remark:** This operation would not be defined if product type Nth-element of `pt` is undefined.

**Note:** In order to implement this function library it would be required that the compiler provides some builtin as e.g. `__builtin_pt_get(N, pt)` that implements product type Nth-element of `pt`.

Add the following section in N4564

---

**Product type algorithms**

---

**Product type algorithms synopsis**
namespace std {

namespace product_type {

    template <class F, class ProductType>
    constexpr decltype(auto) apply(F&& f, ProductType&& pt);

    template <class PT1, class PT2>
    PT1 assign(PT1& pt1, PT2&& pt2);

    template <...PTs>
    constexpr 'see below' cat(PTs&& ...pts);

    template <F, State, class ProductType>
    constexpr State fold_left(ProductType&& pt, State&& state, F&& f);

    template <F, class ProductType>
    constexpr State fold_left(ProductType&& pt, F&& f);

    template <F, class ProductType>
    constexpr void for_each(ProductType&& pt, F&& f);

    template <T, class PT>
    constexpr 'see below' make_from(PT&& pt);

    template <PT1, class PT2>
    PT1& move(PT1& pt1, PT2&& pt2);

    template <PT>
    constexpr 'see below' to_tuple(PT&& pt);

    template <PT>
    void swap(PT& x, PT& y) noexcept('see below');
}

Effects: Given the exposition only function:

```cpp
    template <class F, class PT, size_t... I>
    constexpr decltype(auto) apply_impl(F&& f, PT&& t, index_sequence<I...>) { // exposition only
        return INVOKE(std::forward<F>::(f),
                      product_type::get-I::std::forward<tuple>(
        }
```
In the following paragraphs, let \( Ti \) be the \( i \)th type in \( \text{PTs} \), \( Ui \) be \( \text{remove_reference_t\_<Ti>\_} \), \( pti \) be the \( i \)th parameter in the function parameter pack \( pts \), where all indexing is zero-based and

\[
\text{Requires: For all } i, Ui \text{ shall be the type } cvi PTi, \text{ where } cvi \text{ is the (possibly empty) } i \text{th cv-qualifier-seq. Let } Aik \text{ be } \text{product_type::element<ki, PTi>}. \text{ the } ki \text{th type in } PTi. \text{ For all } Aik \text{ the following requirements shall be satisfied: If } Ti \text{ is deduced as an lvalue reference type, then}
\]

\[\_\text{is_constructible_v<cvii Aik, cvi Aik &> == true, otherwise } \_\text{is_constructible_v<cvii Aik, cvi Aik &> == true.} \]

**TODO: reword this paragraph** Remarks: The types in \( \text{Ctypes} \) shall be equal to the ordered sequence of the extended types \( \text{Args0...}, \text{Args1...}, \ldots \text{Argsn-1...} \)， where \( n \) is equal to \( \text{sizeof...(\text{PTs})} \). Let \( ei \) be the \( i \)th ordered sequence of tuple elements of the resulting tuple object corresponding to the type sequence \( \text{Argsi} \).

**TODO: reword this paragraph** Returns: A tuple object constructed by initializing the \( ki \)th type element \( \text{eik} \) in \( ei \) with \( get<ki>(\text{std::forward\_<Ti>(pti)}) \) for each valid \( ki \) and each group \( ei \) in order.

*Note:* An implementation may support additional types in the parameter pack \( \text{Tuples} \) that support the tuple-like protocol, such as pair and array.

### Function Template product_type::fold_left

\[
\text{template <class F, class State, class ProductType>}
\text{constexpr State fold_left(ProductType&& pt, State&& state, F&& f);}\]

### Function Template product_type::make_from

\[
\text{template <class T, class PT>}
\text{constexpr 'see below' make_from(PT&& pt);}\]

#### Effects: Given the exposition-only function:

\[
\text{template <class T, class PT, size_t... I>}
\text{constexpr T make_from_impl(PT&& t, index_sequence<... I...>)} \{ \text{// exposition only}
\text{return T(product_type::get<0>(\text{std::forward\_<T>(t)}...));}\}
\]

Equivalent to:

\[
\text{return make_from_impl-<T>(\text{forward\_<Tuple>(t)}, product_type::element_sequence_for\_<PTs>);}\]

*Note:* The type of \( T \) must be supplied as an explicit template parameter, as it cannot be deduced from the argument list. - end note -

### Function Template product_type::move

\[
\text{template <class PT1, class PT2>}
\text{PT1\_move(PT1&& pt1, PT2&& pt2);}\]

In the following paragraphs, let \( VPT2 \) be \( \text{remove_cv_t<remove_reference_t\_<PT2>>} \), \( Ti \) be \( \text{product_type::element<ki, PT1> \_} \) and \( Ui \)

\( \text{product_type::element<ki, VPT2>}. \)

**Requires:** Both \( PT1 \) and \( VPT2 \) are ProductTypes with the same size, \( \text{product_type::size<PT1>::value==product_type::size<VPT2>::value} \) and \( \_\text{is_assignable_v<Ti, Ui&> == true \_} \) for all \( i \).

**Effects:** Moves each element of \( pt2 \) to the corresponding element of \( pt1 \).

### Function Template product_type::swap

\[
\text{template <class PT>}
\text{void swap(PT & x, PT & y) noexcept('see below');}\]

*Remark:* The expression inside \( \text{noexcept} \) is equivalent to the logical and of the following expressions: \( \_\text{is_nothrow_swappable_v<Ti>} \) where \( Ti \) is \( \text{product_type::element<ki, PT>} \).
Requires: Each element in $x$ shall be swappable with (17.6.3.2) the corresponding element in $y$.

Effects: Calls `swap` for each element in $x$ and its corresponding element in $y$.

Throws: Nothing unless one of the element-wise `swap` calls throws an exception.

**Function Template `product_type::to_tuple`**

```cpp
template <class PT>
constexpr "see below" to_tuple(PT&& pt);```

Effects: Equivalent to

Change 20.5.1p1 [tuple.general], Header synopsis as indicated.

Replace

```cpp
template <class... Tuples>
constexpr tuple<CTypes...> tuple_cat(Tuples&&... tpls);
```

by

```cpp
template <class... PTs>
constexpr tuple<CTypes...> tuple_cat(PTs&&... pts);
```

Change 20.5.2 [tuple.tuple], class template tuple synopsis, as indicated.

Replace

```cpp
// 20.4.2.1, tuple construction
...
template <class... UTypes>
  EXPLICIT constexpr tuple(const tuple<UTypes...>&);
template <class... UTypes>
  EXPLICIT constexpr tuple(tuple<UTypes...>&&);

template <class U1, class U2>
  EXPLICIT constexpr tuple(const pair<U1, U2>&); // only if sizeof...(Types) == 2

template <class U1, class U2>
  EXPLICIT constexpr tuple(pair<U1, U2>&); // only if sizeof...(Types) == 2

// 20.4.2.2, tuple assignment
...
template <class... UTypes>
  tuple& operator=(const tuple<UTypes...>&);
template <class... UTypes>
  tuple& operator=(tuple<UTypes...>&&);
template <class U1, class U2>
  tuple& operator=(const pair<U1, U2>&); // only if sizeof...(Types) == 2

template <class U1, class U2>
  tuple& operator=(pair<U1, U2>&); // only if sizeof...(Types) == 2

// allocator-extended constructors
...
template <class Alloc, class... UTypes>
  EXPLICIT tuple(allocator_arg_t, const Alloc& a, const tuple<UTypes...>&);
template <class Alloc, class... UTypes>
  EXPLICIT tuple(allocator_arg_t, const Alloc& a, tuple<UTypes...>&&);
template <class Alloc, class U1, class U2>
  EXPLICIT tuple(allocator_arg_t, const Alloc& a, const pair<U1, U2>&);
template <class Alloc, class U1, class U2>
  EXPLICIT tuple(allocator_arg_t, const Alloc& a, pair<U1, U2>&&);
```

by
Constructor from a product type

Suppress in 20.5.2.1p3, Construction \([\text{tuple.cnstr}]\)

\[ \text{tuple} \langle \text{PT} \langle \text{class} \rangle \rangle \]

Replace 20.5.2.1p15-26, Construction \([\text{tuple.cnstr}]\) by

\[ \text{tuple} \langle \text{class} \rangle \]

Let \( \text{Ui} \) be the \( i \)th type in a template parameter pack named \( \text{UTypes} \), where indexing is zero-based.

Effects: For all \( i \), the constructor initializes the \( i \)th element of \( \ast \text{this} \) with \( \text{std::forward<Ui>(product_type::get<i>(u))} \).

Remarks: This constructor shall not participate in overload resolution unless \( \text{PT} \) is not \( \text{tuple<Types...>} \), \( \text{PT} \) is a \( \text{product type} \) with the same number elements than this tuple and \( \text{is_constructible} \langle \text{value} \rangle \) is true for all \( i \). The constructor is explicit if and only if

Assignment from a product type

Suppress in 20.5.2.2p1, Assignment \([\text{tuple.assign}]\)

\[ \text{tuple} \langle \text{class} \rangle \]

Replace 20.5.2.2p9-20, Assignment \([\text{tuple.assign}]\) by

\[ \text{tuple} \langle \text{class} \rangle \]

Let \( \text{Ui} \) be the \( i \)th type in a template parameter pack named \( \text{UTypes} \), where indexing is zero-based.

Effects: For all \( i \), assigns \( \text{std::forward<Ui>(product_type::get<i>(u))} \) to \( \text{product_type::get<i>(\ast this)} \).

Returns: \( \ast \text{this} \)

Remarks: This function shall not participate in overload resolution unless \( \text{PT} \) is a \( \text{product type} \) with the same number elements than this tuple and \( \text{is_assignable<Ti&, const Ui&>} \langle \text{value} \rangle \) is true for all \( i \).

[Note: We could as well say equivalent to \( \text{product_type::copy} \langle \text{std::forward<PT>(u)}, \ast \text{this}\rangle; \text{return } \ast \text{this} \). end note]

Allocator-extended constructors from a product type

Change the signatures
by

```cpp
template <class Alloc>
  tuple(allocation_arg_t, const Alloc & a, const tuple &);
template <class Alloc>
  tuple(allocation_arg_t, const Alloc & a, tuple &);
  template <class Alloc, class... UTypes>
  EXPLICIT tuple(allocation_arg_t, const Alloc & a, const tuple<UTypes...> &);
  template <class Alloc, class... UTypes>
  EXPLICIT tuple(allocation_arg_t, const Alloc & a, tuple<UTypes...> &);
  template <class Alloc, class U1, class U2>
  EXPLICIT tuple(allocation_arg_t, const Alloc & a, pair<U1, U2> &);
  template <class Alloc, class U1, class U2>
  EXPLICIT tuple(allocation_arg_t, const Alloc & a, pair<U1, U2> &&);
  template <class Alloc, class U1, class U2>
  EXPLICIT tuple(allocation_arg_t, const Alloc & a, pair<U1, U2>);
```

Adapt the definition of `std::tuple_cat` in [tuple.creation] to take care of product type.

Replace `Tuples` by `PTs`, `tpls` by `pts`, `tuple` by `product type`, `get` by `product_type::get` and `tuple_size` by `product_type::size`.

```cpp
std::tuple_cat
```

```cpp
template <class... PTs>
constexpr tuple<CTypes...> tuple_cat(PTs&&... pts);
```

[Note: - We could as well say equivalent to `product_type::cat<tuple>({std::forward<PT>(pts)...});` end note]

Adapt the definition of `std::apply` in [tuple.apply] to take care of product type.

Replace `Tuple` by `PT`, `t` by `pt`, `tuple` by `product type`, `std::get` by `product_type::get` and `std::tuple_size` by `product_type::size`.

```cpp
std::apply
```

```cpp
template <class F, class PT>
constexpr decltype(auto) apply(F&& f, PT&& t);
```

[Note: - We could as well say equivalent to `product_type::apply(std::forward<F>(f), std::forward<PT>(t));` end note]

**std::pair**

Change 20.3.2 [pairs.pair], class template pair synopsis, as indicated:

Replace

```cpp
template <class... Args1, class... Args2>
pair(piecewise_construct_t,
  tuple<Args1...> first_args,
  tuple<Args2...> second_args);
```

by

```cpp
template <class PT1, class PT2>
pair(piecewise_construct_t, PT1 first_args, PT2 second_args);
```

Add
```
```
```cpp
template <class PT>
pair& operator=(PT&& u);
```
```
```cpp
```
piecewise constructor

Replace

```cpp
template <class ... Args1, class ... Args2>  
  pair<piecewise_construct_t,  
    tuple<Args1 ...> first_args, tuple<Args2 ...> second_args>;  
```

by

```cpp
template <class PT1, class PT2>  
  pair<piecewise_construct_t, PT1 first_args, PT2 second_args>;  
```

Constructor from a product type

Add

```cpp
template <class PT>  
  EXPLICIT constexpr pair<PT&& u>;  
```

Let $U_i$ is `product_type::element_t<i, remove_cv_t<remove_reference_t<PT>>>`.  

Effects: For all $i$, the constructor initializes the $i$th element of `*this` with `std::forward(product_type::get(u))`.  

Remarks: This function shall not participate in overload resolution unless $PT$ is not `pair<T1, T2>`, $PT$ is a product type with 2 elements and `is_constructible<Ti, U_i>::value` is true for all $i$. The constructor is explicit if and only if `is_convertible<U_i&&, Ti>::value` is false for at least one $i$.

Assignment from a product type

```cpp
template <class PT>  
  pair& operator=(PT&& u);  
```

Let $U_i$ is `product_type::element_t<i, remove_cv_t<remove_reference_t<PT>>>`.  

Effects: For all $i$ in $0..1$, assigns `std::forward(U_i)(product_type::get<i>(u))` to `product_type::get<i>(*this)`.  

Returns: `*this`  

Remarks: This function shall not participate in overload resolution unless $PT$ is a product type with 2 elements and `is_assignable<Ti&, const U_i&>::value` is true for all $i$.  

[Note: - We could as well say equivalent to `product_type::copy(std::forward<PT>(u), *this); return *this` end note]

### std::array

Add

```cpp
template <class PT>  
  array& operator=(PT&& u);  
```

Let $U_i$ is `product_type::element_t<i, remove_cv_t<remove_reference_t<PT>>>`.  

Effects: For all $i$ in $0..1$, assigns `std::forward(U_i)(product_type::get<i>(u))` to `product_type::get<i>(*this)`.  

Returns: `*this`  

Remarks: This function shall not participate in overload resolution unless $PT$ is a product type with $N$ elements and `is_assignable<T6, const U_i&>::value` is true for all $i$.  

[Note: - We could as well say equivalent to `product_type::copy(std::forward<PT>(u), *this); return *this` end note]

### Implementability

This is not just a library proposal as the behavior depends on Structured binding P0217R3. There is no implementation as of the date of the whole proposal paper, however there is an implementation for the part that doesn't depend on the core language `PT_impl` emulating the cases 1 and 2. The standard library has not been adapted yet neither.
Open Questions

The authors would like to have an answer to the following points if there is any interest at all in this proposal:

- Do we want the `std::product_type::size` / `std::product_type::get` functions?
- Do we want the `std::product_type::size` / `std::product_type::element` traits?
- Do we want to adapt `std::tuple_cat`?
- Do we want to adapt `std::apply`?
- Do we want the new constructors for `std::pair` and `std::tuple`?
- Do we want the `pt_size / pt_get` operators in a future proposal?

Future work

Add other algorithms on Product Types

```cpp
front
front: PT(T) -> T
```

```cpp
back
back: PT(T) -> T
```

```cpp
is_empty
is_empty : PT(T) -> bool
```

Add other algorithms on TypeConstructible Product Types

The following algorithms need a `make<TC>{args...}.factory P0338R0`

If the first product type argument is TypeConstructible from the `CTypes` then return an instance of it; otherwise construct a `std::tuple`.

```cpp
cat
cat: TCPT(T)... -> TCPT(T)
```

```cpp
transform
transform: TCPT(T)... -> TCPT(T)
```

```cpp
drop_front
drop_front: TCPT(T) -> TCPT(T)
```

```cpp
drop_back
drop_back: TCPT(T) -> TCPT(T)
```

```cpp
group
group
TCPT(T) -> TCPT(TCPT(T))
```

```cpp
insert
insert: TCPT(T) x unsigned x T -> TCPT(T)
```

... Product Types views and lazy algorithms

Based on Range views for homogeneous Ranges `Range-v3`, views for heterogeneous sequences `Boost Fusion` define Product Types views, adaptors, ...

Tagged Product Types

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- **PT_impl** Product types access emulation and algorithms

- **SWAPPABLE** ProductTypes must be Swappable by default

- **PT_SWAP** ProductTypes must be Swappable by default

- **Range-v3**
  - [https://github.com/ericniebler/range-v3](https://github.com/ericniebler/range-v3)