

Type Safety and UB Prevention Architecture

C

SafeTypeConversion

- bit_cast : safe conversion
- fallback_memcpy : template fallback

benefits:
no strict aliasing violations
no undefined behavior
zero cost optimization
sanitizer clean

Replaces unsafe reinterpret_cast.
Use cases:
type punning
bit manipulation
SIMD data loading

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ComparisonSafety

- approx_equal_before : hardcoded epsilon
- approx_equal_after : numeric_limits epsilon

benefits:
type specific precision
correct machine epsilon
float and double appropriate

Applies to:
Vec approx_equal
Mat approx_equal
Quaternion approx_equal
Vec safe_normalized
Vec from_homogeneous

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UbsanSafety

- checks :
 - type punning
 - strict aliasing
 - null deref
 - signed overflow
 - unaligned access

result:
zero errors
sanitizer clean

Test command:
fsanitize undefined
Run matrixlib gtests

C

AsanSafety

- checks :
 - buffer overflow
 - use after free
 - use after return
 - memory leaks
 - invalid alignment

result:
zero errors
no leaks
proper alignment

Test command:
fsanitize address
Run matrixlib gtests

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QuaternionSafety

- vec_accessor : safe return by value
- set_vec : direct assignment
- rvo : return value optimization

benefits:
eliminates type punning UB
passes UBSan clean
same performance as unsafe code

Safe vec() returns a new Vec3f.
No aliasing or reinterpret_cast.

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StaticVerification

- replaces_is_pod : future proof
- verified_types : trivially copyable

guarantees:
memcpy safe
DMA compatible
C interface safe
binary serializable

std_is_pod deprecated in C++20
removed in C++23
std_is_trivially_copyable works in all versions

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EdgeCaseTests

- singular_matrices
- nan_inf_handling
- zero_normalization
- quaternion_aliasing
- cross_product_edges
- simd_alignment

total_tests = 18

Designed to trigger sanitizers.

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SimdSafety

- type_guarded_casts : compile time checks
- neon_safety : float only aligned
- cmsis_safety : vendor tested API

guarantees:
memory layout compatible
safe intrinsic usage
trivially copyable verification

Verified with static_assert on
std::is_trivially_copyable<VecFloatN>.

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SafetyDocumentation

- type_punning_fixes
- bit_cast_usage
- quaternion_vec_safety
- simd_safety_verification
- testing_instructions
- best_practices
- ci_cd_integration

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SafetyImprovements

- summary_of_changes
- files_modified
- impact_analysis
- performance_verification
- next_steps